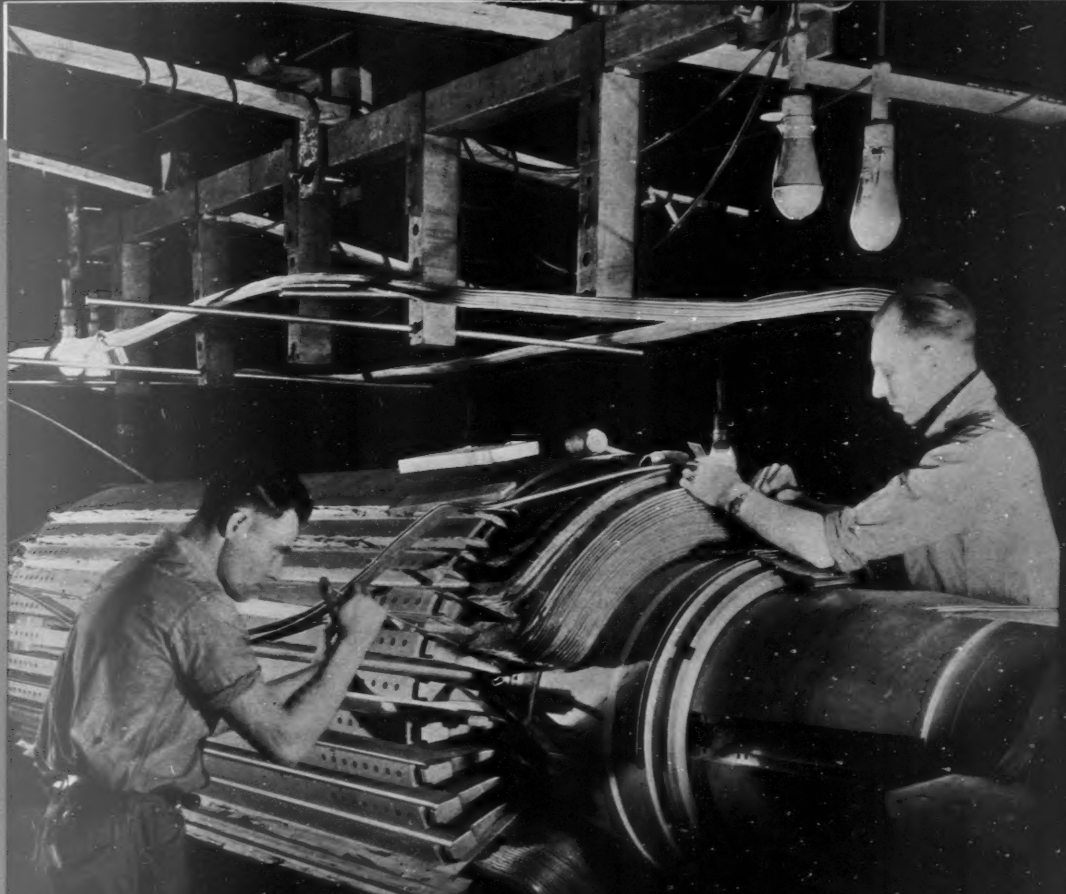
ALLIS-CHALMERS

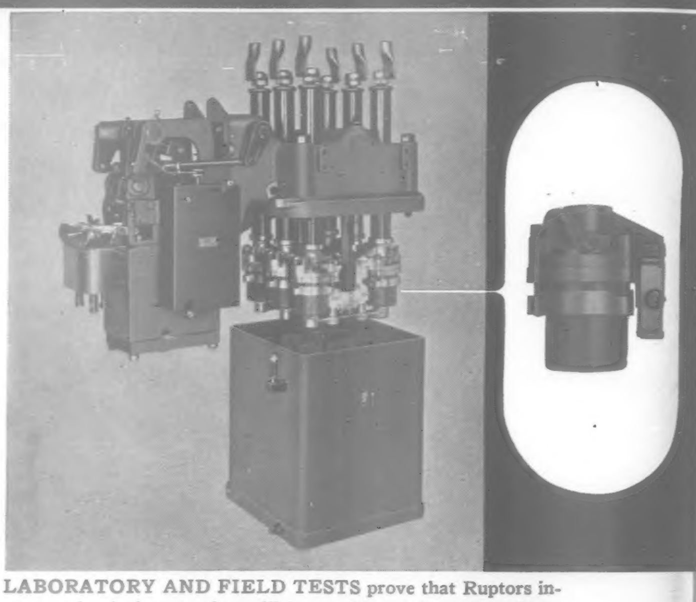
ELECTRICAL REVIEW

December • 1938



Winding a Turbo Rotor.

RUPTORS QUENCH ARCS *FAST!*



LABORATORY AND FIELD TESTS prove that Ruptors increase circuit interrupting efficiency. Shown here is a Type DZ-40, 3 pole, 600 amp, 15 kv oil circuit breaker with Ruptor.

Their "QUICK-QUENCH" Action CUTS Oil Carbonization and Contact Deterioration to a Minimum!

● When a short circuit occurs, it's got to be interrupted in a hurry! That's the *why* of the oil circuit breaker. That's what you get in Allis-Chalmers Oil Circuit Breakers with Ruptors, for high voltage systems.

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You get consistent operation without constant attention. Ruptors enable an oil circuit breaker to handle many more circuit interruptions before requiring inspection and renewal of oil and contacts. And when service is necessary, it's a quick and easy job! Ruptors are accessible for inspection and testing . . . take less time to service than other circuit breakers.

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ALLIS-CHALMERS

ELECTRICAL REVIEW

C O N T E N T S

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A MAJOR INSTALLATION OF REGULATING TRANSFORMERS

• Henry R. Kurth, Assistant Chief System Operator
BOSTON EDISON CO. . . . BOSTON, MASS.

The use of regulating transformers in large sizes is relatively recent in New England although the need for such equipment at several locations in the interconnected systems has long been recognized.

The improvement of service continuity and the operating economies afforded by closed loop operation of major transmission lines could not properly be realized because of the uncontrollable power flow which caused overload trip-outs and uneconomical load transfer, because of the lack of regulating equipment for correction of phase angle displacement and voltage differences.

• Closed loop offered advantages to interconnected systems

In the Boston area, a joint economic study of the New England Power and Boston Edison systems indicated that closed loop operation offered many advantages. Accurate control of power flow would allow continuous closure of the lines around the circuit from the L Street Generating Station to the Charles Leavitt Edgar Generating Station in the Boston Edison System to Millbury and Tewksbury on the New England Power System to Melrose and Malden in the North Boston area and then back to L Street.

One advantage to be gained through closed loop operation was the controlled supply of primary power to the Boston Edison system or the exchange of surplus power between systems via the Millbury, Sudbury, and North Boston interconnections without causing uneconomical, inadvertent power flow at any point. Other advantages were increased stability of the system interconnections and additional capacity for mutual support during emergency conditions.

With the economic value of closed loop operation established, engineering studies were pursued to determine the magnitude and nature of the corrective equipment needed.

AT LEFT: Axial entry low pressure blading for a 3,600 rpm high capacity, high vacuum steam turbine.

• Past experience showed wide phase angle and voltage differences

Past records indicated that during the freshet season, when the power flow was from northern New England hydro stations toward the southeastern load centers, a wide difference in phase angle existed between the Tewksbury and L Street Station busses, with Tewksbury leading. Conversely, during long, dry seasons, when heavy loads prevailed in the industrial cities of northern Massachusetts, the power flow tendency was from the Boston Edison system toward Tewksbury, with L Street Station about 20 degrees in advance of Tewksbury. Exhaustive studies on the calculating board of the Massachusetts Institute of Technology led to the choice of regulating transformers which would permit a phase shift of 25 degrees lead or lag.

Similar studies of voltage correction in order to control the flow of reactive kva indicated that a 10 per cent variation from normal would be adequate, even under the prevailing different voltage levels of 24 kv at L Street Station and 23 kv at Malden.

• Site chosen

Although the corrective equipment could have been installed at any point in the closed loop, the desire for both minimum investment and best conditions of control dictated the selection of the location at the L Street Station in the 24 kv tie lines to the North Boston area. Minimum investment was insured because this 24 kv tie is the lowest voltage and lowest capacity interconnection between systems. Optimum control conditions were produced because adjustment of phase angle and voltage could be made by the same operator who controlled the turbine governors at the L Street Station and the loading on the tie lines from the L Street Station to Edgar Station.

• Regulating equipment selected

The regulating equipment selected comprises three 10,400 kva, three-phase units, one in each of the 24 kv underground cables to the Revere and

Malden substations of the North Boston section of the New England Power system. Each unit is suitable for both phase angle and voltage adjustment under load and is controlled independently or in a group from the L Street control room. The electrical design utilizes a primary winding connected in delta across the 24 kv line which is used to excite two low voltage secondary windings. These secondaries are provided with equipment for tap changing under load and are interconnected so as to allow variation of both in-phase and quadrature induced voltages.* The resultant secondary voltage is superimposed on the primary circuit through a series transformer and thus shifts the phase angle and/or voltage of the original primary supply as desired.

The in-phase voltage adjustment above and below normal has 32 steps for the overall 37 per cent variation, with approximately 1⅛ per cent change per step. The quadrature phase angle adjustment above and below normal also has 32 steps for the overall 50 degree phase shift, with approximately 1½ degree phase shift per step. In each case, one-half the steps are obtained with a preventive auto-transformer connected across adjacent taps and designed for continuous duty operation.

The tap changer for in-phase voltage control consists of a quick-break, spring-operated, oil-immersed dial switch, utilizing a motor to energize the springs and a dog to release the mechanism when adequate spring tension is obtained so that rapid operation is assured. By means of a reversing switch the required number of steps are obtained with but nine dial switch contacts.

The tap changer for phase angle control consists of a cam-operated oil circuit breaker which interrupts each side of the auto-transformer in turn while the intermittent gear-driven dial switch is rotated. The same operating mechanism is also utilized to lower or raise the oil circuit breaker tank so that inspection is expedited.

Both the in-phase voltage and phase angle control tap changing mechanisms have interlocks to prevent out-of-step operation between banks and also to disconnect the control circuits when mechanical adjustments are being made.

The regulating transformers are connected integral with the lines and are equipped with oil-filled cable pothead boxes to avoid any exposed primary connections. Oil-immersed, three-position disconnecting switches are provided to allow the cable to be separated from the transformer and connected to test bushings during kenotron testing of cables, or to allow grounding of the cable during repair work.

The use of a bottom gasket rather than the conventional top gasket on the main case and the novel gasket design have resulted in negligible oil leakage. The space above the oil is filled with nitrogen gas to prevent oil sludging, and an expansion tank accommodates changes in oil volume. The expansion tanks are of unusual construction in that they provide an oil seal which prevents breathing under all ordinary conditions. No separate supply of nitrogen is required. The oil level indicators are of the magnetic type and are readily visible from a distance.

• Service operation

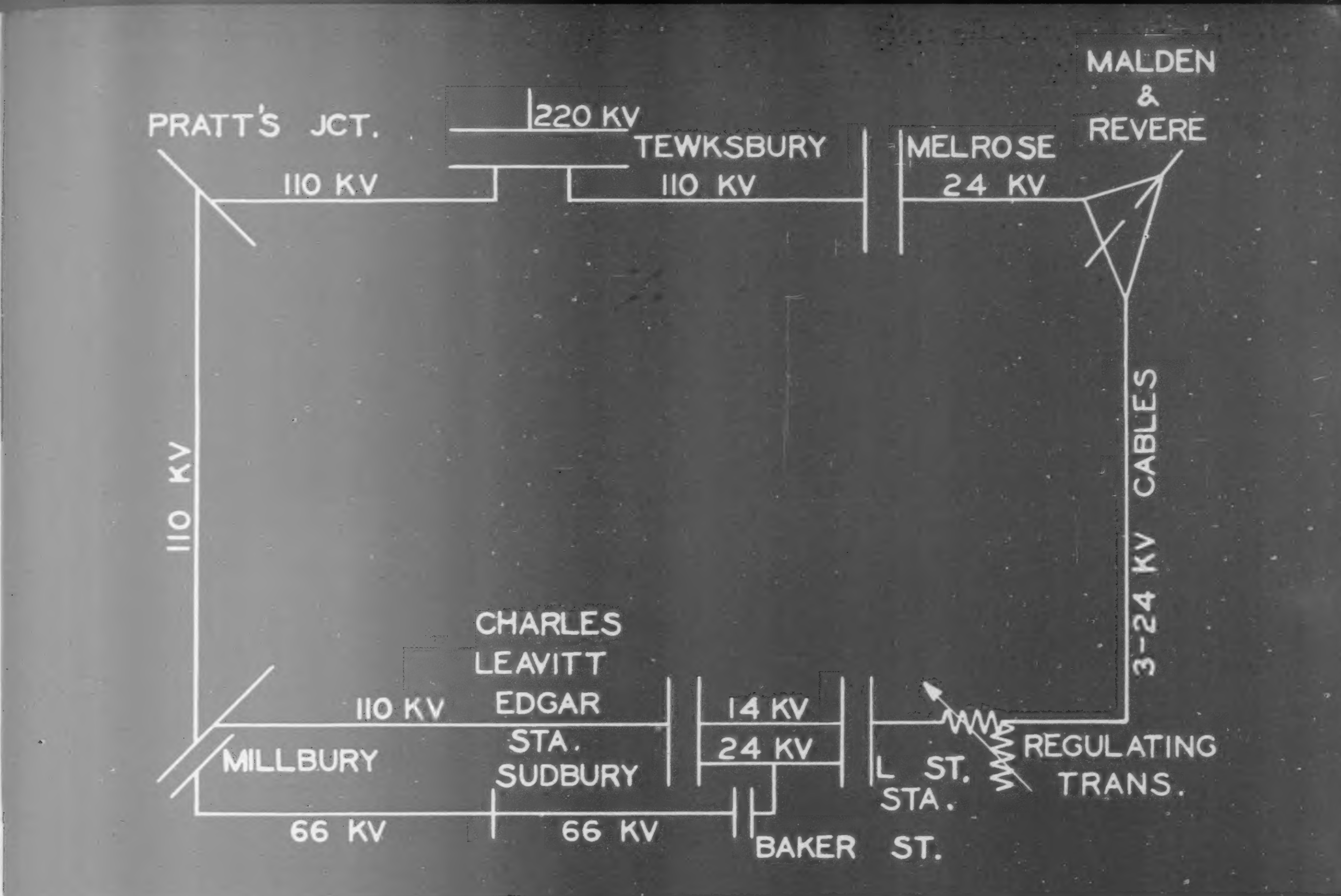
It has been very interesting to note the range over which the voltage and phase angle tap changers have been called upon to operate. On several occasions during the freshet season of 1937, the phase angle control was advanced to about 20 degrees in order to hold the power flow into L Street station via the North Boston interconnection to the scheduled amount. On one occasion an unusual situation arose at one of the North Boston stations in which it became desirable to transfer the load from the normal 23 kv source to another source which was 30 degrees behind in phase relation due to transformer connections. The transfer was successfully made without service interruption by retarding the 23 kv bus the available 25 degrees, utilizing the regulating transformer on one line.

Under normal operation, group control is ordinarily used, and consequently uniform load distribution is kept on all three lines.

The operating record of these regulating transformers since their installation early in 1937 has been unusually fine, with a negligible amount of outage time. The number of operations on the voltage and phase angle tap changers approximate 16,000 and 40,000 respectively, on each of the three units.

ABOVE: Major economies and accurate control of power flow were obtained by the closure of the transmission line loop through the New England Power and Boston Edison systems, around a circuit from the L Street Station to the Charles Leavitt Edgar Station, to Millbury, Pratts Junction, Tewksbury, Melrose, Malden, Revere, and back to L Street. Continuous loop closure, previously impracticable due to phase-angle conditions, was accomplished through installation of three 10,400 kva, 24 kv regulating transformers (AT RIGHT), integral with the cables from L Street to Malden and Revere, and equipped for tap changing under load over a 50 degree quadrature phase angle and 40 percent in-phase voltage range.

* See Allis-Chalmers ELECTRICAL REVIEW, December 1937, "Transformers for Combined Voltage and Phase Angle Control Under Load," by L. H. Hill, for detailed connections.


MALDEN
&
REVERE
PRATT'S JCT.
220 KV
TEWKSBURY
MELROSE
110 KV
110 KV
24 KV
110 KV
3-24 KV CABLES
CHARLES
LEAVITT
EDGAR
STA.
SUDBURY
110 KV
14 KV
24 KV
MILLBURY
L ST.
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REGULATING
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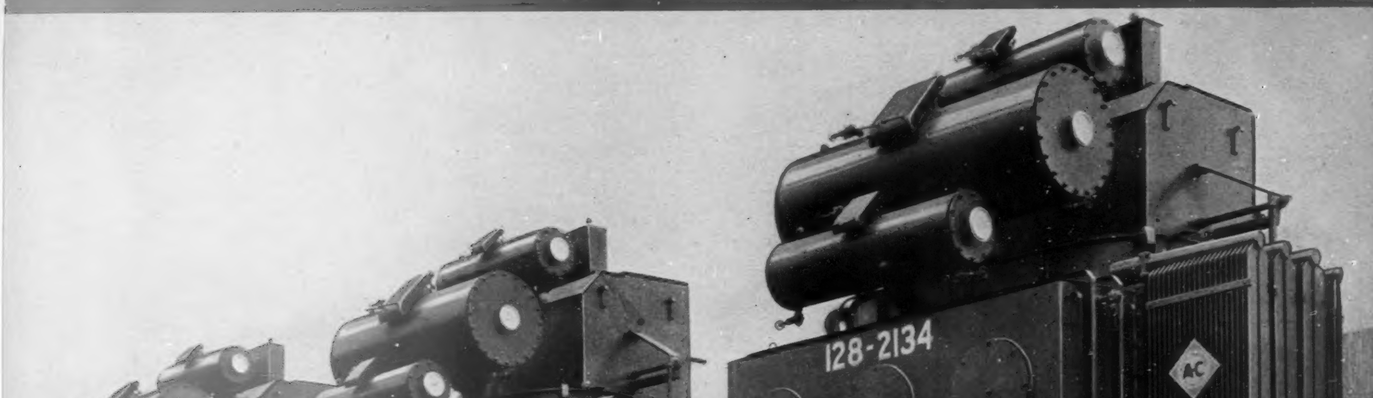
66 KV
66 KV
BAKER ST.


128-2134
128-2132
PHASE ANGLE
TAP CHANGER
PHASE ANGLE TAP
CHANGER OIL SWITCH

WHAT GOES ON IN THE MERCURY ARC RECTIFIER

• D. Journeaux
PATENT ATTORNEY . . . ALLIS-CHALMERS MANUFACTURING CO.

Mercury arc rectifiers have now been in regular commercial operation in this country for some thirteen years, and many power system operators have become familiar with their functioning, yet to many the rectifier remains a mysterious piece of apparatus. There is nothing in it that revolves or moves back and forth which might be grasped by the mechanically minded, and the possibility of a multiplicity of anodes operating in a common tank appears most puzzling. Yet the rectifier is first cousin to the vacuum tubes used in every radio set, and is the big brother of the mercury vapor tube supplying plate current in many of the more elaborate sets.

However, the use of a radio set does not imply an extended knowledge of physics. Therefore, as much of the electron theory will be outlined here as may be useful in explaining the mode of operation of rectifiers.

Mercury arc rectifiers, together with vacuum tubes and copper oxide rectifiers, are characterized by the common useful property of offering a relatively low resistance to the flow of electric current in one direction and a relatively high resistance, practically amounting to infinity, to the flow of current in the other direction. When connected in a circuit comprising a source of alternating current, a rectifier accordingly closes the circuit for current impulses in one direction of flow and opens the circuit for current impulses tending to flow in the other direction. The current thus selectively conducted appears to have been "rectified," hence the name of rectifiers given to unilateral or at least asymmetrical conductors.

Although the construction of the mercury arc rectifier has been the subject of numerous and detailed publications, let it be recalled that, contrary to the belief once expressed to the writer by a fellow engineer, the rectifier is not chock-full of liquid mercury. There is indeed a little mercury forming the so-called negative terminal or cathode electrode at the bottom of the rectifier tank, but current conduction through the rectifier is from a so-called positive electrode or main anode, or from a number of main anodes through mercury vapor to the cathode. This may not seem strange, since at least liquid mercury is a good conductor of electricity, but this is not the reason why current may flow through mercury vapor. It can flow equally easily, under proper circumstances, through other vapors or through gases such as neon, argon, or even air at atmospheric pressure.

AT LEFT: One of the Men in White carefully inspects the anode rings for a mercury arc rectifier. Note the hospital-like cleanliness surrounding the handling of the parts.

The fact is that while the conduction of electricity through solids and liquids has so long been commonplace as to be taken for granted, the more newly utilized conduction through vapors and gases takes place fundamentally in the same manner. While vapors and gases are known to be good electric insulators, the problem of using them to conduct current economically is simply a matter of selecting proper operating conditions.

• Nature of electricity and matter

While the characteristics of conduction of electricity through matter primarily result from the nature of electricity, they, of course, also depend on the nature of matter. Because these natures cannot be ascertained by mere inspection, the best that can be done is to imagine a hypothetic constitution of electricity and of matter as fully consistent as possible with the known mechanical and electrical properties evidenced by matter under all possible natural, or even unnatural, circumstances.

It was thus imagined, with sufficiently good reason, that electricity consists of an accumulation of minute equal particles or charges of which practically all, the so-called electrons, have the same properties and repel one another like the molecules of a gas under pressure. Evidence was also obtained of the presence of charges equal in value to that of the electron but which are attracted by electrons — the so-called protons. Judging from its properties, matter appears to be some kind of "frozen" electricity, consisting of elementary particles or atoms each comprising a nucleus of protons or of protons and electrons surrounded by a number of electrons circulating in orbits as the planets circulate around the sun. The atoms of the ninety-two different elements found in nature are characterized by the number of their protons and electrons. The atoms themselves are assumed to have a rectilinear movement, the speed of which

varies with temperature, the direction of movement being continually changed by collisions between atoms. In general, the atoms, however, do not travel singly but are united with definite numbers of similar or different atoms to form so-called molecules.

In the normal or neutral condition of the atoms, the charges of the protons and of the electrons of each atom neutralize each other exactly. In good conductors, such as metals, however, the electrons are considered to be somewhat loosely bound to the nucleus. If a source of electric current, a direct-current generator for example, is connected between two points of a conductor as, for instance, the terminals of a direct-current motor, these electrons are withdrawn by the generator from the so-called positive terminal of the circuit, accelerated through the generator by its magnetic field, and delivered to the so-called negative terminal of the circuit. There is thus produced a concentration of "free" electrons at the negative terminal and a depletion of electrons at the positive terminal. The repulsion between electrons is therefore more intense at the negative terminal than at the positive terminal and results in a tendency of the electrons to circulate from the negative terminal to the positive terminal to restore the neutral condition of the atoms of the conductor. This tendency is called the potential difference or pressure or voltage between the terminals and results in excess electrons of the negative terminal passing from atom to atom, with which they momentarily unite, until they return to the positive terminal.

• Rectification in mercury vapor arc

If the positive terminals of the generator and of the motor are separated, the generator terminal being connected to the main anode of a rectifier and the motor terminal to the rectifier cathode, the circuit illustrated in Fig. 1 is obtained. At first the generator circuit is opened by the rectifier, because the atoms of the mercury vapor contained in the rectifier tank are too few and too slow and hence come in contact with one another too seldom to pass on the electrons from the cathode to the anode.

There are several ways of rendering the mercury vapor sufficiently conductive. For example, as illustrated in Fig. 1, the rectifier may be provided with an ignition anode connected to the cathode through a source of direct current (battery). The ignition anode is momentarily immersed into the cathode pool, whereupon electrons flow from the battery through the cathode to the ignition anode and the ignition resistor back to the battery. The ignition anode is then withdrawn from the cathode. When contact between the ignition anode and the cathode is about to be broken, the ignition current is concentrated through a mere filament of mercury, and if the ignition current is sufficiently intense — a few amperes are generally necessary — the mercury filament is finally vaporized by the current.

The mercury vaporized from the filament is momentarily under high pressure and at high temperature. Under these conditions, electrons accumulated at the cathode by the battery pass easily from the hot spot so produced at the surface of the cathode to the vapor into which they are said to be emitted. These electrons, called primary electrons, frequently collide with the highly concentrated atoms of the mercury vapor and thereby split these neutral atoms into free electrons and atoms lacking electrons or positive ions. As these free or secondary electrons in turn collide with more mercury vapor atoms, still more electrons and ions are released. The result is a cumulative process called ionization.

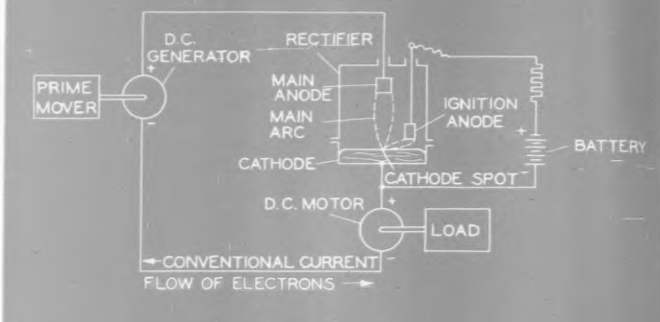


Fig. 1

Meanwhile the voltage still impressed between ignition anode and cathode causes electrons from the battery to continue to accumulate at the cathode. These electrons repel the primary and secondary electrons of the mercury vapor, which are also attracted by the positive charge of the atoms of the ignition anode robbed of electrons by the battery. After a series of collisions with vapor atoms, the primary and secondary electrons reach the ignition anode from which they are recirculated by the battery. Some electrons also recombine with ionized vapor atoms to reform neutral atoms. The remaining atoms eventually strike the cathode pool where they find their complement of electrons and are retained by the liquid mercury.

The path of the ionized vapor, near the surface of the pool, tends to be localized and terminates at a so-called cathode spot or at several such spots. The ionized vapor stream flowing to the cathode loses its kinetic energy upon reaching the surface of the pool, where this energy appears as heat. The cathode spot, or spots, is thus maintained at incandescence. As the cathode continues to emit primary electrons in dense high temperature vapor by a self-sustaining process after the ignition anode is completely withdrawn from the cathode pool, the continuous flow of a so-called excitation current is

maintained through the rectifier in a more or less definite path or excitation arc.

The generator, which functions similarly to the battery, transmits electrons from the main anode or, otherwise expressed, brings the main anode to a positive potential with respect to cathode potential. Electrons released from the vapor atoms therefore also are attracted to the main anode to form a second arc, the main arc, between the main anode and the cathode spots. The connection of the generator with a current-consuming device, such as a direct-current motor, is thus completed as though through a continuous solid conductor.

If, however, the polarity of the generator is reversed, the main anode is brought to a negative potential with respect to the cathode and is loaded with a concentrated charge of electrons. These electrons are not emitted in material amounts into the vapor because of the inherently restricted faculty of the anode material, iron or graphite, to emit electrons and because of its relatively low temperature. The rectifier thus fails to conduct current between the main anode and the cathode and constitutes an open circuit for the generator.

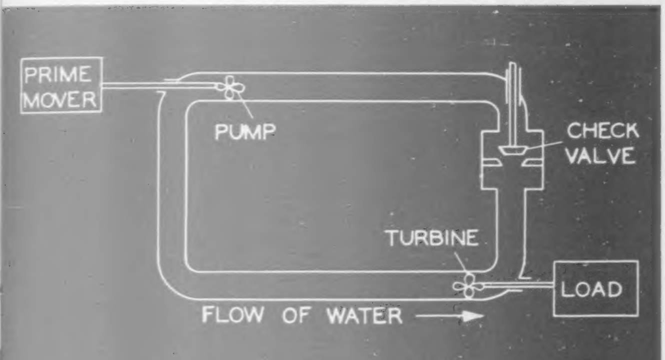


Fig. 2

• Rectifier acts as a check valve

The rectifier is therefore a unilateral conductor in the nature of a check valve permitting the flow of electrons in one direction and checking it in the other direction. This valve action is due to the fact that while the cathode, once "excited" by the excitation arc, can emit electrons as well as receive them the anode can only receive electrons. The seat of the valve action is thus at the anode and this action is not, as is sometimes expressed, a property peculiar to mercury vapor.

If the direct-current generator is replaced by an alternating-current generator, as illustrated in Fig. 3, during the so-called positive half cycles, the main anode is brought to a positive potential and allows the flow of current from the generator to the motor as when a direct-current generator is used. During the intervening negative half cycles the anode is at a negative potential, and the generator circuit is open at the rectifier. The alternating-current generator accordingly delivers a succession of unidirectional current impulses to the motor. In this figure and in the following figures, the necessary ignition circuit is implied but is omitted for clearness.

• Fundamental action of grids

The flow of electrons from the cathode to the main anode while the anode is at a positive potential may also be prevented by impressing a negative potential on a third electrode arranged adjacent to the anode in or around the main arc path. This electrode (called a grid electrode because of its usual grid-like construction) functions fundamentally as an anode. When the grid is at a negative potential, it not only fails to emit electrons but it also is charged with electrons which repel the free electrons of the vapor more intensely than they are attracted by the positive charge of the main anode. These free electrons are thus unable to reach the anode, and the anode remains without current.

When the grid is at a positive potential, it attracts electrons to itself to constitute a grid current. These electrons increase the ionization of the vapor in the vicinity of the grid and of the main anode and therefore facilitate the flow of electrons between the cathode and the main anode. The grid may be made negative during a large number of cycles of the anode generator to prevent completely the passage of anode current, and it may also be made negative during only a part of each cycle to reduce the average anode current.

• Hydraulic analogy of rectifier operation

The functioning of multiple anode rectifiers is fundamentally the same as that of the single anode rectifier above described, but the circuit becomes more complicated and the flow of current more difficult to follow. To render the rectifier operation clearer, use may be made of the observation that in our universe there is an apparent degree of order so that otherwise unrelated phenomena may be represented by the same mathematical relationships. When two unequally familiar phenomena present such similarity it is then natural to explain the lesser known phenomenon by reference to the more commonplace. Accordingly, it has long been the practice of educators and writers to compare the invisible and intangible flow of electric current to the visible and tangible flow of a ponderable and at least somewhat elastic fluid such as water.

For example, the flow of electrons through the circuit illustrated in Fig. 1 may be compared to the flow of water through the circuit illustrated in Fig. 2. The direct-current generator, which is reversible and may or may not deliver current while excited

at normal voltage, is preferably represented by a reversible pump of the impositive type, such as the propeller type. The direct-current motor is similarly represented by a turbine of the propeller type, and the rectifier is represented by a simple check valve.

In a similar manner, the circuit illustrated in Fig. 3 may be represented by the hydraulic system of Fig. 4, in which the alternating-current generator is represented by a propeller-type pump given a harmonic reversing movement from the prime mover through a suitable crank mechanism or its equivalent. The pump produces an alternating head in the conduit, but the valve permits the flow of water in only one direction so that the turbine is caused to rotate in only one direction.

Although the flow of water through the pump is pulsating, the flow through the turbine may be rendered substantially uniform by means of what might be called a hydrodynamic filter. A number of different kinds of such filters may be imagined. For example, the filter may consist of a long section of pipe in series with the pump and the turbine and a by-pass across the turbine closed by a piston held by a spring. The inertia of the large volume of water contained in the long pipe section maintains the flow of water for a short time after the pump has reversed and thus lengthens the water flow impulses without, however, being able to make them overlap. During these periods, however, water flows upward through the by-pass and exerts pressure on the piston, which compresses the spring. In the intervals between water flow impulses through the pump, the spring moves the piston downward and thereby produces local impulses in the circuit formed by the by-pass and the turbine.

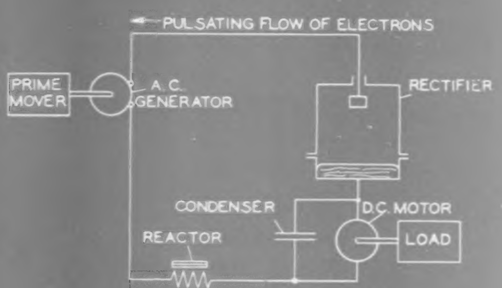


Fig. 3

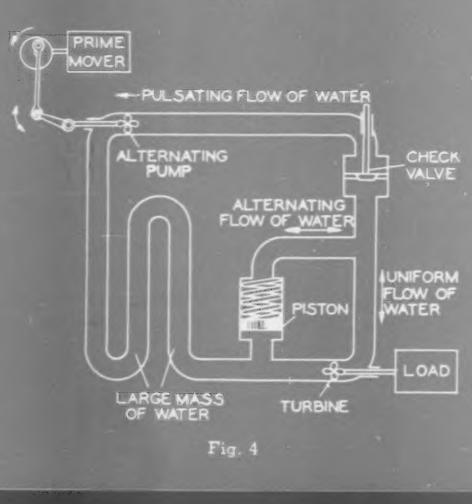


Fig. 4

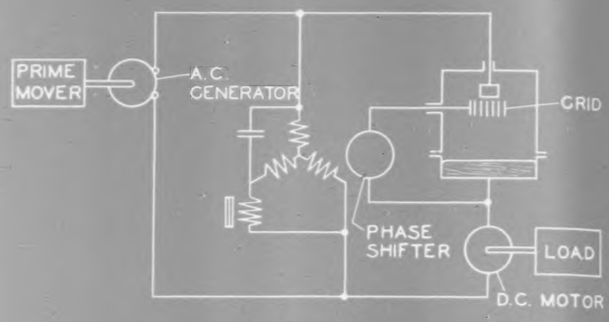


Fig. 5

In the turbine these impulses overlap the impulses produced by the pump and, if the system is well designed, the turbine will receive an almost constant flow of water. While hydraulic engineers would probably use a pair of air bottles instead of the piston, the latter was chosen as it offers a greater similarity to the condenser of Fig. 3 of which it is the hydraulic equivalent. The long pipe section corresponds to the series reactor of Fig. 3. The reactor and condenser form an electric filter which smooths the pulsations of the current in the direct-current motor by a process entirely comparable to the process of operation of the hydrodynamic filter of Fig. 4.

A hydraulic equivalent may also be found for the system, as illustrated in Fig. 5, in which the grid is energized from the generator through a phase shifter to cause the grid voltage to lag behind the generator voltage by an adjustable angle. When the generator renders the anode positive with respect to the cathode, the flow of current is delayed until the grid likewise becomes positive with respect to the cathode. The periods of current flow are consequently reduced to a length of less than one-half cycle and the average current through the motor is correspondingly reduced.

The corresponding hydraulic arrangement is illustrated in Fig. 6, in which the check valve representing the rectifier may be prevented from opening by a bell crank. The bell crank is moved out of the path of the valve stem by a push rod and a crank driven from the prime mover through a clutch which is adjustable to give any desired angular relation between the pump crank and the valve crank. Hence the valve may be maintained closed for any desired length of time while the pump is already exerting pressure tending to lift the valve and is thereafter released for a half cycle. Of course, the valve recloses as soon as the flow of water tends to reverse, but it could not be forced

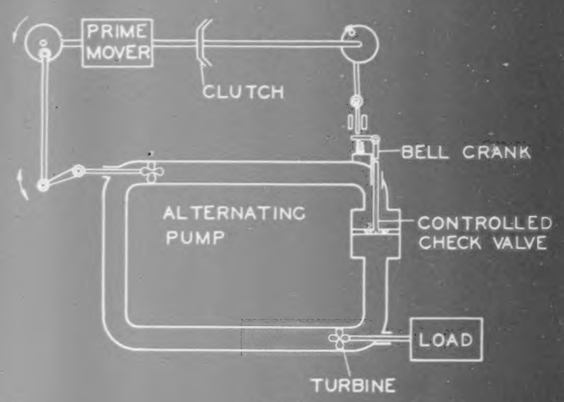


Fig. 6

to reclose sooner since the bell crank has no closing action.

• Polyphase rectifiers

The rectifiers illustrated in Figs. 1, 3, and 5, are known as single-phase half-wave rectifiers, and their hydraulic equivalents were considered first on account of their simplicity. In general, however, rectifiers are of the polyphase half-wave type illustrated in Fig. 7. The source of supply is usually a three-phase generator and is connected to the rectifier through a three-phase to six-phase transformer. The system generally utilizes a single rectifier tank having at least six anodes connected to the transformer secondary terminals, and a single cathode connected to the motor or other direct current consumer. Since the valve action of the rectifier resides at the anodes while current may pass in either direction through a cathode, the multiple-anode rectifier is the equivalent of a group of single-anode rectifiers of the type illustrated in Figs. 1, 3, and 5 having their cathodes connected together.

In either case the system corresponds to the hydraulic system illustrated in Fig. 8. The transformer is represented by a group of hydraulic pump-turbine sets having a harmonic reversing movement as a result of the flow of alternating currents of water between the pumps driven by the prime mover and the turbines of the sets. While the current flow produced by each pump of a set is pulsating, the two pumps of a set operate alternately so that the turbine of the set transmits power during both positive and negative half cycles of water flow. The rectifier is represented by a set of six valves connected to a common reservoir. In their harmonic movement the six pumps exert pressures varying in sequence between a maximum positive value and an equal maximum negative value.

It is easy to see that at any instant the pump giving the highest pressure in the proper direction pumps water through the turbine driving the load and through the reservoir. This pump also exerts a pressure on the outlets of the five other pumps which overcomes their own discharge pressures and which therefore maintains the valves of these pumps against their seats. This process continues for an interval of one-sixth of a cycle, after which the pressure exerted by another pump becomes maximum, and this pump then delivers water and forces the valve of the first operating pump to reclose. This sequence of operations is repeated for all six pumps, which thus pump water one after the other as long as the prime mover operates.

Similarly, in the rectifier the anodes are successively brought to alternating potentials, and the anode momentarily having the highest potential attracts electrons from the cathode. The potential difference between the operating anode and the cathode is not large, so that the remaining anodes are then negative with respect to the cathode and do not operate since they repel the electrons of the mercury vapor. In the system illustrated, each anode is provided with a grid and the grids are charged positively by a battery connected to the cathode to facilitate the operation of the anodes. The grid polarity may also be reversed to prevent the electrons from reaching the anodes. When this is done, the anode then operating continues to function because the large number of ions produced in its arc path neutralizes the effect of the grid electrons. The other anodes, however, are immediately prevented from again carrying current. When the operating anode becomes negative with respect to the cathode, it is prevented from carry-

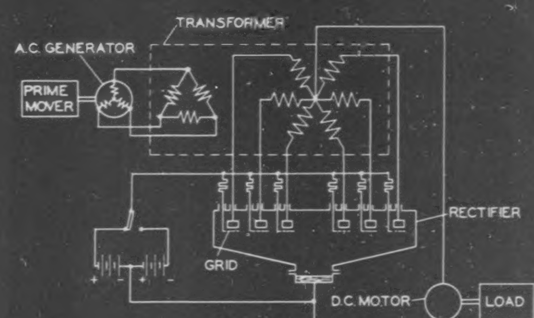


Fig. 7

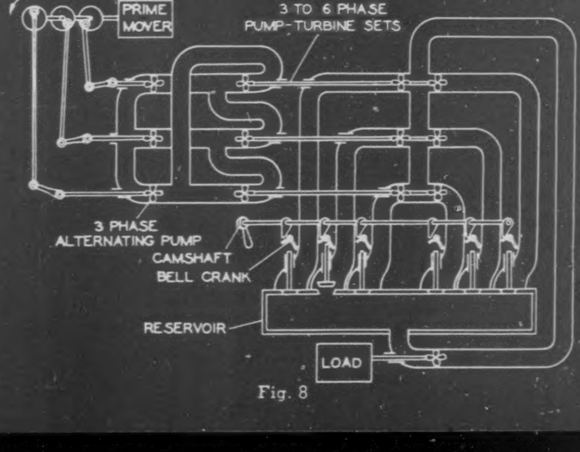


Fig. 8

ing current further by its valve action, and its grid thereupon also prevents its repeated operation. The rectifier is then completely inoperative.

• Backfires

It may occasionally happen that a non-active anode momentarily emits electrons, which action might result from the anode being struck by a falling drop of condensed mercury or from some other causes difficult to ascertain. Since this anode is then negative with respect to the operating anode and to the cathode, the flow of electrons takes place from the faulty anode to the normally operating anode, and the transformer is thus short circuited. Other anodes may also feed into the faulty anode while it is negatively energized from the transformer.

This fault is readily cleared by reversing the polarity of the grids by means of the hand switch. As explained above, when the grids have become negatively energized they prevent the inactive anodes from carrying current upon reaching their highest positive potential in turn. Only the anodes carrying current, including the faulty anode, continue to operate until their potential difference reverses. The current between anodes then momentarily drops to zero, and the grids of these anodes

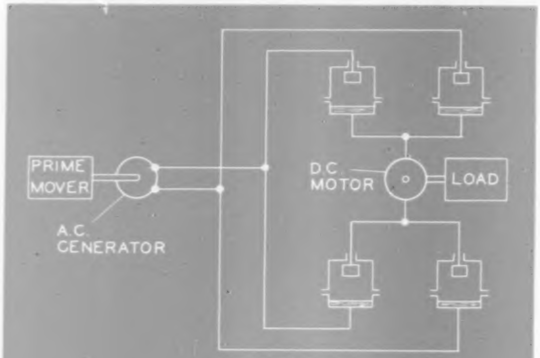


Fig. 9

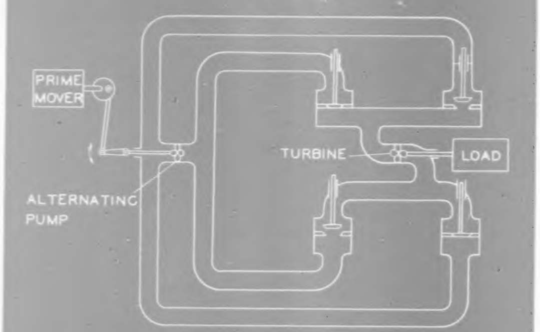


Fig. 10

BELOW: Two 2500 kw. 630 volt, manually operated mercury arc power rectifiers installed for a large subway system.

also prevent their current from being re-established. All the anodes are then blocked, and the rectifier may be returned to its normal operation by re-applying a positive potential on the grids.

This rectifier failure, or backfire, corresponds to the momentary failure of a valve to close in the system of Fig. 8. This failure results in water being pumped from the correctly operating pumps one after the other back to the pump which has a valve stuck in the open position. This situation may be relieved by turning the cam shaft to release the bell cranks of all the valves. The bell cranks of those valves which are then shut immediately prevent these valves from reopening. The valve through which water is delivered to the defective valve remains open until the flow of water tends to reverse therethrough, whereupon it closes and is maintained closed by its bell crank To complete the comparison it must, however, be assumed that the defective valve then also recloses by itself and is maintained closed like the remaining valves. The system is then out of operation and may be restarted by releasing the valves by means of the cam shaft.

• Other uses

Full wave single-phase and three-phase rectifying systems are also used when the amount of power converted is relatively small. These systems require the use of several cathodes at different potentials which cannot be arranged in a single tank since the cathodes have no valve action. The system may then comprise single-anode mercury arc rectifiers or other types of rectifiers such as copper-oxide rectifiers. Fig. 9 illustrates a single-phase full wave rectifier and Fig. 10 the corresponding hydraulic system. The analogy between the two is evident from the previous description.

Hydraulic analogies have no doubt been found useful in that they give the reader a sense of familiarity with electric phenomena which he may not attain otherwise, and sometimes the solution of problems in electric circuits may be found easier by first considering the equivalent hydraulic circuit. It should, however, be borne in mind that the similarity between electric and hydraulic circuits is not always perfect and that factors which may be ignored in one circuit may become important in the other. The solutions obtained with hydraulic circuits should therefore be scanned critically before being applied to electric circuits. Analogies between electric circuits and mechanical systems of springs and rotating or reciprocating elements may also be found useful.

BELOW: These twenty rectifiers with a total capacity of 54,000 kw are the largest single installation on this continent. The Alcoa Aluminum Co., at Maryville, Tenn., has these rectifiers connected in pairs to transformers, making this installation the highest number of rectifiers ever built in parallel on a common circuit.

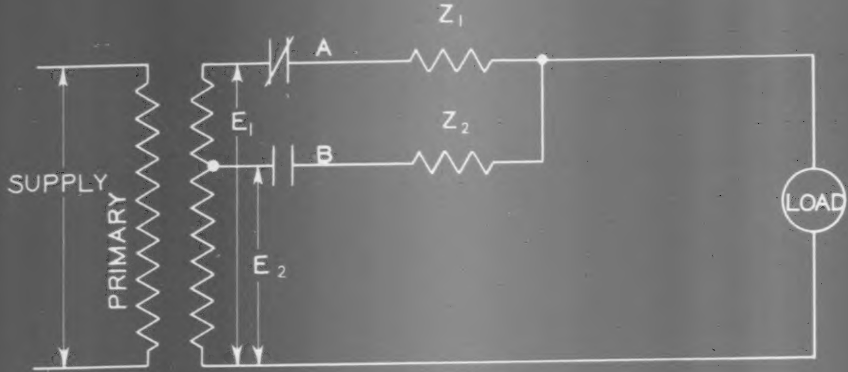


Fig. 1

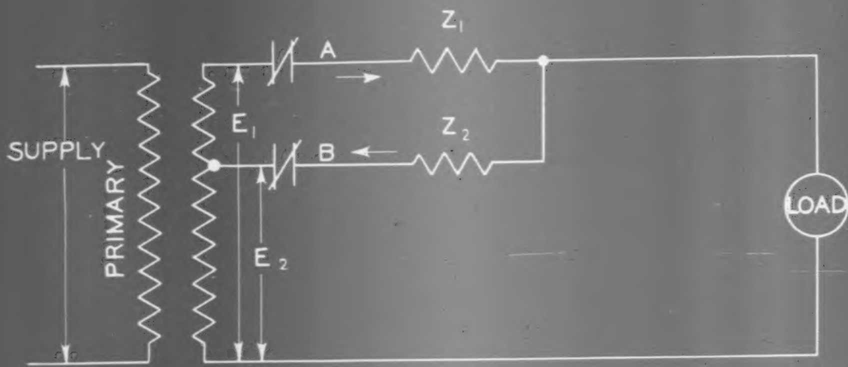


Fig. 2

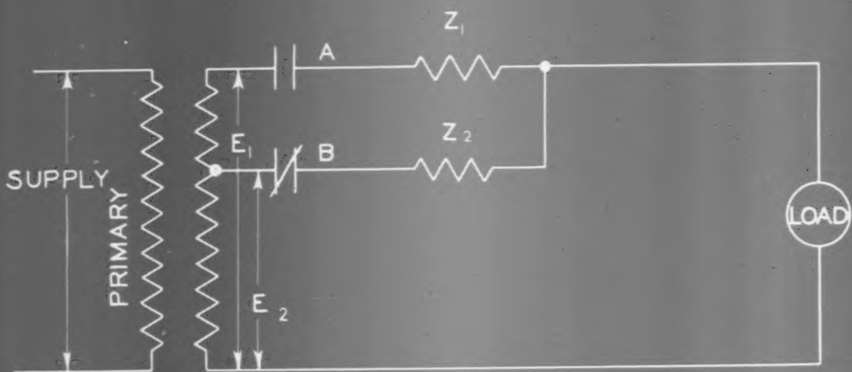


Fig. 3

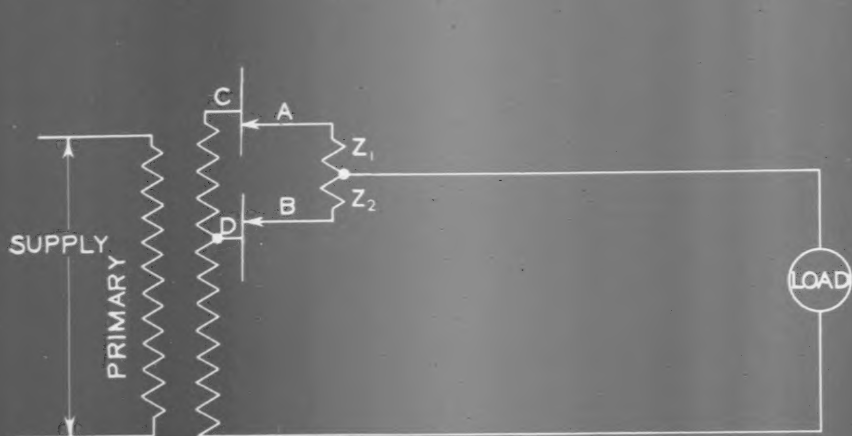


Fig. 4

ENGINEERING FUNDAMENTALS

CHANGING TAPS UNDER LOAD ON TRANSFORMERS

There are various circuits in common use for changing from one tap to another on a transformer without de-energizing the transformer or disconnecting it from the load. The fundamental requirements for load tap changing are:

(1) The circuit must never be interrupted even momentarily;

(2) At no time shall excessive current flow in any part of the circuit;

(3) The voltage drop through the circuit must not be excessive at any time.

A fundamental circuit for load tap changing is shown in Figs. 1, 2, and 3. In Fig. 1, Switch A is closed, Switch B open, and the load is supplied through the impedance Z_1. The voltage at the load is the voltage E_1 less the impedance drop through the impedance Z_1. The next step in changing from the voltage E_1 to the voltage E_2 is shown in Fig. 2, in which Switch B has been closed. In this position both Switches A and B are closed, and a part of the load current flows through Z_1 and a part through Z_2. The voltage at the load in a properly designed unit will be intermediate between the voltages E_1 and E_2. For the connections shown in Fig. 2, there will be a local circulating current through Z_1 and Z_2 in addition to the load current. The direction of flow of this circulating current is indicated by the arrows in Fig. 2. The voltage causing current to flow in this local circuit is equal to E_1 minus E_2, and the impedance of the circuit is equal to Z_1 plus Z_2 plus the impedance from the primary winding.

Figure 3 shows the final position in which the voltage at the load is equal to E_2 minus the impedance drop through Z_2.

• Selection of impedances

In order to secure proper operating characteristics, values of Z_1 and Z_2 must be properly chosen. For operation under the connections of Fig. 1 and Fig. 3 it is desirable that Z_1 and Z_2 be as low as possible so that the voltage drop through these impedances due to the load current will be as low as possible. However, in order to secure low circulating current for the condition of operation shown in Fig. 2, it is desirable that Z_1 and Z_2 be made as high as possible. Obviously, with these two conflicting desirable characteristics, the selection of Z_1 and Z_2 must be a compromise. With values of Z_1 and Z_2 properly selected, the circuit shown can be made to fulfill the requirements listed for load tap changing. Figs. 1, 2, and 3 provide circuits which are never interrupted. Z_1 and Z_2 can be proportioned so that the impedance drops through them in Figs. 1 and 3 are not excessive and so that the circulating current for Fig. 2 is not excessive.

A method which was once used for securing low impedance to load currents and high impedance to circulating currents was to construct Z_1 and Z_2 as iron core reactors without air gaps. This construction had the objection of causing a peaked voltage wave with a very high maximum value. Present-day reactors for this service are designed with air gaps in the core so that, regardless of the current, the impedance remains constant over the normal range of operation.

The circuits shown illustrate the fundamental principles of load tap changing. Other circuits for load tap changing have similar characteristics and can be considered as modifications of this fundamental circuit. Modifications generally consist of switches to form additional circuit connections and of additional impedances to those shown.

• Most common circuit

The most common circuit in actual use for load tap changing equipment utilizes an auto-transformer reactor with a tap at the center. This circuit is illustrated in Fig. 4. The five positions of the tap changing mechanism in moving from Position C to Position D are indicated in the table. One advantage of this circuit is that when both taps are on Position C the auto-transformer reactor is short-circuited, and the only impedance drop in the circuit is the very small impedance of the auto-transformer. Another advantage is that since Z_1 and Z_2 are on the same core Position 3 produces a voltage half way between Positions 1 and 5. Positions 2 and 4 are normally transient positions and are not used for continuous operation. The mechanical construction of the dial switch for making these connections is suggested by Fig. 4. Ordinarily the stationary contacts C and D are made wide and the movable contacts A and B are made narrow. These contacts are so spaced that the connections shown can be produced by sliding contacts A and B with fixed spacing across contacts C and D.

The circuit of Fig. 4 generally provides the most desirable operating characteristics, but other circuits are sometimes used to simplify the operating mechanism.

POSITION	CONNECTIONS	
	A TO	B TO
1	C	C
2	C	–
3	C	D
4	–	D
5	D	D

Fig. 5

ON FOLLOWING PAGES: Inspecting low pressure cylinder blading of a 25,000 kw, 1800 rpm steam turbine.

RECENT TRENDS IN THE DESIGN OF POWER TRANSFORMERS

• L. H. Hill, Engineer-in-charge
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

During the past fifteen years, it is safe to say there have been more changes in power transformer design than in all the years prior to that time. In such a rapidly changing situation it is often worth while to pause and consider the natures of the various important trends.

• Improved mechanical construction of internal parts

Transformers have sometimes been humorously described as "chunks of iron with some wires wrapped around and rags stuck in between." Some of the earlier ones did look just about like that. A power transformer of modern manufacture is quite different. In recent years there has been a definite tendency to make power transformers more and more mechanical in appearance through careful consideration of such details as rigid bracing of windings, stiff clamping structures, leads encased in machine-wound tubing, and the like, as illustrated in Fig. 1 and Fig. 2.

• Designing for impulse strength

An outstanding trend in the design of power transformers has been the engaging subject of designing them to withstand specific impulse voltages rather than to follow the practice of designing them to merely withstand normal frequency test voltages.

It has also been found desirable to base the determination of the insulation strength a transformer shall have upon the impulse strength of other insulation in and adjacent to the station. Consequently, we find transformer insulation being specified as "greater than a standard rod gap of —— inches" when tested under given conditions with a specified impulse test wave. It has been only recently that the various laboratories have been able to come to some agreement as to the actual impulse voltages corresponding to the several test gaps, and test levels may now be specified in impulse voltages instead of inches of gap length.

The impression that a transformer is adequately protected against lightning if it is equipped with a bushing gap set equal to the gap setting used in the impulse test has been frequently entertained. Unfortunately, this is not true, and the characteristics of the rod gap under impulse conditions need be thoroughly understood before it is depended upon for lightning protection.[1]

The impulse test requirement for transformer insulation strength is that it be designed to be stronger than its test gap when tested under certain specified conditions. The fallacy of depending upon these values for protection was later appreciated when the fact was considered that the rod gap possesses a time lag characteristic which allows higher and higher voltages for shorter and shorter periods of time, whereas the time lag curve of

(1) "Service Gaps for Transformer Bushings," by F. W. Bush, Allis-Chalmers ELECTRICAL REVIEW, Dec. 1936.

AT LEFT: Lowering core and coils of a 20,000 kva, single-phase 132 kv power transformer into the tank.

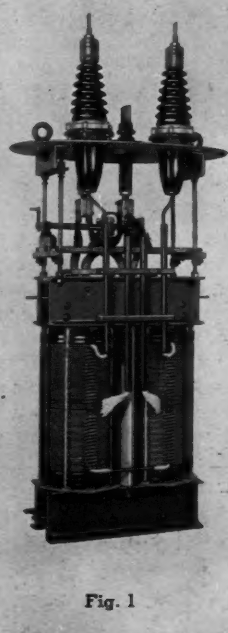


Fig. 1

Fig. 2

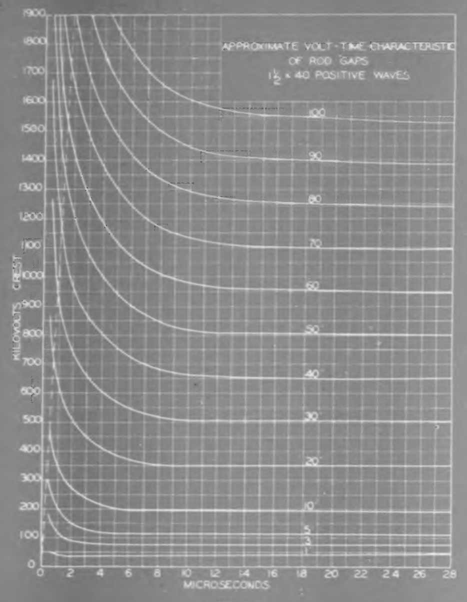


Fig. 3

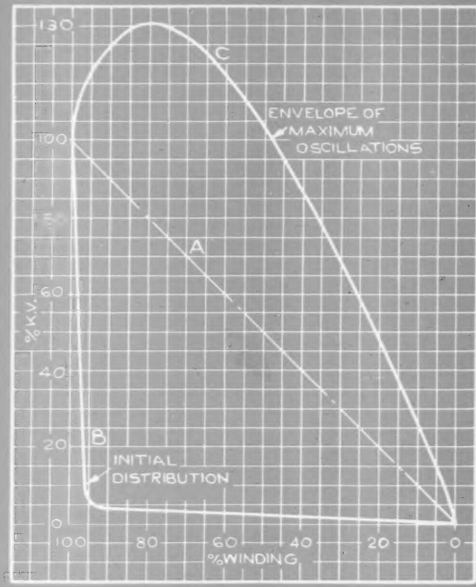


Fig. 4

insulation is very much flatter. Fig. 3 shows the approximate volt-time characteristics of various rod gaps when tested with the 1½-40 positive wave. The minimum flashover of the test gap will occur in from five to twenty micro-seconds, depending on the gap length. If, however, a voltage wave of higher magnitude or steeper wave front is applied to the gap, the gap will flash over at a considerably higher voltage but in a shorter time. Since the transformer insulation has a much flatter time-lag characteristic, if a transformer is protected only by the standard test gap, it may be subjected to voltages much higher than the normal test level. Accordingly, where gaps are to be used for protection, the gap setting must be considerably reduced below the original A. I. E. E. test figure. Values as low as 50 per cent of the test gap setting have been successfully used.

The use of reduced gap settings will materially increase the protection of the transformer, but even where they are used the transformer may not be entirely protected against such very steep voltage waves as those caused by direct hits in close proximity to the transformer.

• The use of dielectric flux control

With the trend to design transformers to withstand impulse voltages has also come a trend to design the windings to minimize internal oscillations. When a high voltage power transformer is operating at normal frequency under steady-state conditions, the voltage across the windings is uniformly distributed. For example, if it is assumed that one end of the high voltage winding is solidly grounded, the voltage at the grounded end will be zero; the voltage at the line end, 100 per cent; and the voltage at the middle, 50 per cent. This is shown graphically in Curve A of Fig. 4.

But under impulse conditions, or when a voltage surge strikes a transformer winding, the voltage may or may not be distributed uniformly over the winding. For instance, it is possible for the voltage to be distributed as in Curve B of Fig. 4. It will be noted in this case 95 per cent of the applied voltage is impressed across but 5 per cent of the winding, which gives 95 divided by 5, or 19, times the voltage stress that would be obtained with uniform voltage distribution.

It may be shown that the ratio of series capacitance to ground capacitance affects the initial voltage distribution[2] so that the factors in design which affect these capacitances must also be considered. In the high voltage core type of construction, the high voltage winding is made up of a relatively large number of small coils having comparatively small capacity between coils but large capacity to ground. To secure reasonable proportions, the core type transformer requires a large number of small coils of small area between coils and a large area to ground and to the low voltage winding. This arrangement results in low series capacity and comparatively high capacity to ground.

In the shell form of design, there are a comparatively fewer number of coils, but they are of larger size and consequently larger area, and therefore the series capacity is much larger with respect to the ground capacity; hence, the initial voltage distribution is better. The use of a small number of coils of large area is of course possible in the shell form not only because the proportions of core and coils make this possible, but also because solid insulation can be introduced between the coils without affecting oil circulation through the wind-

(2) "Circular Coil Shell Type Transformer Construction for Large and High Voltage Power Transformers," by L. H. Hill, Allis-Chalmers ELECTRICAL REVIEW, Sept. 1936.

ings; whereas, in the core type of design, this is not possible without affecting oil circulation.

To improve the voltage distribution across the face of the coils in a circular coil shell type transformer, a static plate is introduced. The static plate consists of a flat copper sheet, which is insulated and installed the same as any other coil in the transformer and hence does not introduce additional potential hazards, affect oil circulation, or otherwise complicate the transformer. Its use spreads the line potential uniformly across the first coil, since the capacity per unit area of all parts of the plate to the first coil is the same and of comparatively low value. If no such plate were used, the impulse current would have to pass through all of the capacities between turns in series in order to pass from the outside turn of the first coil to the inside turn. High capacitive reactance and consequently high voltage drop would then be experienced.

In core type transformers, the relatively poor voltage distribution is of comparatively little importance for low voltage applications, because the windings can be easily insulated to withstand the conditions imposed. For high voltage transformers, such as those 110,000 volts and above, the problem of providing the necessary insulation is more difficult unless the voltage distribution approximates a straight line. To improve the voltage distribution in high voltage core type transformers, additional electrostatic capacity, called "shields," is sometimes added. These shields have the effect of increasing the series capacity with respect to the shunt capacity to ground. By this means, points well down in the winding are raised closer to line potential by bringing plates connected to the line up close to the points concerned.

A comparison of the mechanical details of the means for accomplishing the desired result in both the core and shell types of transformers will show the relative difficulty in obtaining good voltage distribution in the two cases.

• Increased use of forced air blast equipment

The addition of forced air blast equipment to power transformers has been increasing in popularity. By the addition of this equipment, the kva capacity of medium and larger size units can be increased about one-third, and the smaller units, about one-fourth. Compared with the increased capacity obtained, the cost is nominal. The forced air blast system employed for practically all modern power transformers consists of a number of small fans, or blowers, as shown in Fig. 5 instead of one large blower as has been used formerly. The advantages of the multiple-blower system over the single-blower type are quite obvious — lower cost, higher efficiency, lower losses, greater flexibility, and less danger of complete loss of the forced air blast equipment.

• Inert gas protection

There has also been a noticeable growth in the use of inert gas protection. Inert gas protection reduces oil maintenance and minimizes the dangers of fire and explosion in case of internal trouble in the transformer or fire in the station. An inert gas system supplants the use of the ordinary expansion tank system on a transformer, and, with the exception of the possibility of the maintenance of the inert gas system itself becoming a burden, there are no disadvantages over the expansion tank type. Fig. 6 illustrates schematically a widely used system[3] which operates at practically atmospheric pressure, without mechanical valves of any kind and without the constant replenishment of gas or other materials.

A tank of similar construction to the expansion tank commonly used on oil-filled transformers is divided into two parts, as shown in Fig. 6. The top of one section connects to the gas space in the main transformer, and the top of the other opens to the atmosphere. A large oil seal isolates the two sections from each other.

When the oil in the main transformer tank expands because of an increase in temperature, the pressure in the gas space above the oil increases slightly, and thus the oil level in the closed half of the gas expansion tank is lowered while that in the open half is raised, as indicated. This additional gas space added to the gas space in the main tank

(3) "Inert Gas Protection for Transformers," by L. H. Hill, Allis-Chalmers ELECTRICAL REVIEW, March 1937.

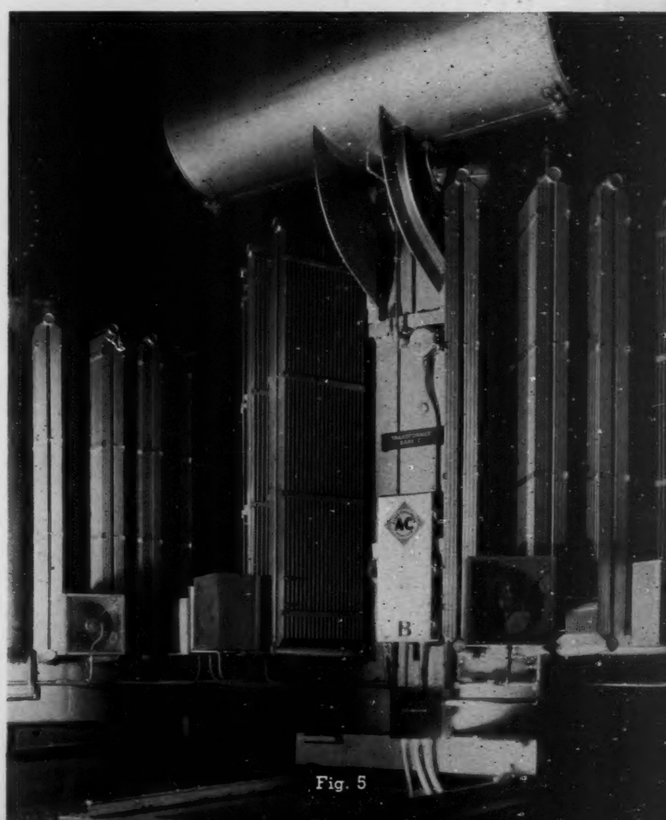


Fig. 5

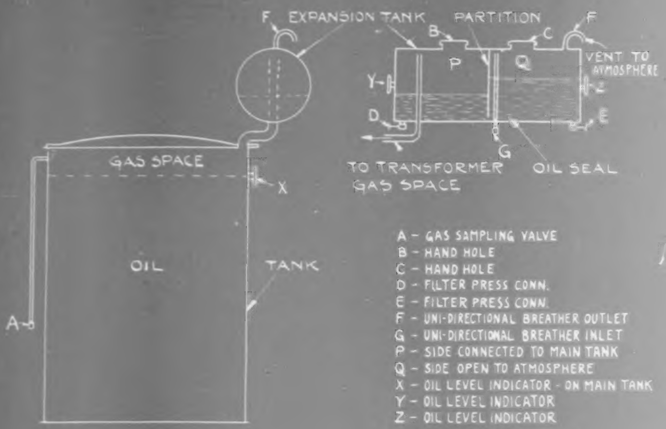
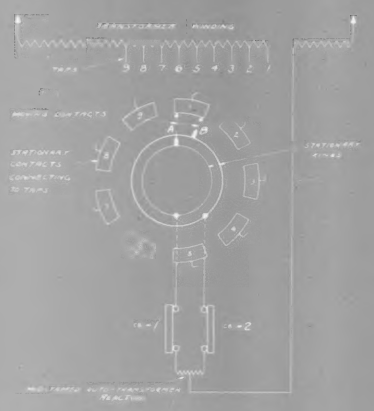


Fig. 6



SEQUENCE OF OPERATIONS FROM POSITION No. 1 TO POSITION [illegible] ASSUMING 2½% VOLTAGE BETWEEN TAP 1 and TAP [illegible]

Position No.	Percent Winding [illegible] Circuit	Connections			
		A to Tap	B to Tap	CB No. 1	CB No. 2
1	100	1	1	Closed	Closed
		1	1	Closed	Open
		[illegible]	2	Closed	Open
		1	[illegible]	Closed	Closed
		1	2	Open	Closed
		[illegible]	2	Open	Closed
2	97½	2	2	Closed	Closed

SWITCH POSITIONS FOR VARIOUS TAP POSITIONS

Position No.	Percent Winding [illegible] Circuit	Moving Contacts A and B Connected To								
		1	2	3	4	5	6	7	8	9
1	100	X								
[illegible]	97½		[illegible]							
3	95			X						
4	92½				X					
5	90					X				
6	87½						X			
7	85							X		
8	82½								X	
9	80									X

Fig. 7

permits considerable change in oil level in the main tank with but slight increase in pressure in the gas space and without breaking the oil seal in the expansion tank. As the oil cools down, the reverse action takes place while the liquid seal in the expansion tank effectively isolates the gas above the oil in the main tank from the atmosphere.

Once the oxygen in the gas space and that which comes out of the oil have been removed, the system will maintain low oxygen content indefinitely without attention. If the initial oxygen is not removed by blowing out with nitrogen, the oxygen content in the gas space will gradually and automatically be reduced to a small value. The amount of sludging of the oil during this period is negligible.

The tank for the inert gas system can be mounted in the usual position for an expansion tank, as in Fig. 6, or it can be mounted on the side of the main tank, or it can even be entirely separate from the transformer.

• More tap changing under load

Power transformers equipped with tap changing under load equipment are finding increasing favor, and rapid strides have been made in the development of equipment of this nature to make it more and more simplified, more compact, and less costly. There is a growing demand for providing smaller and smaller units with tap changing under load equipment, tending to combine the feeder regulator with the supply transformer where new substations are being built. In the smaller sizes, completely automatically controlled units — in some cases, with line drop compensation — are becoming important additions on the lines of many electric systems.

Fundamentally, the schemes of operation are practically all the same, using the single-winding method with a preventive auto-transformer, usually with a tap in the middle. Fig. 7 indicates the general scheme of operation. Fig. 8 illustrates typical equipment using the circuit breakers No. 1 and

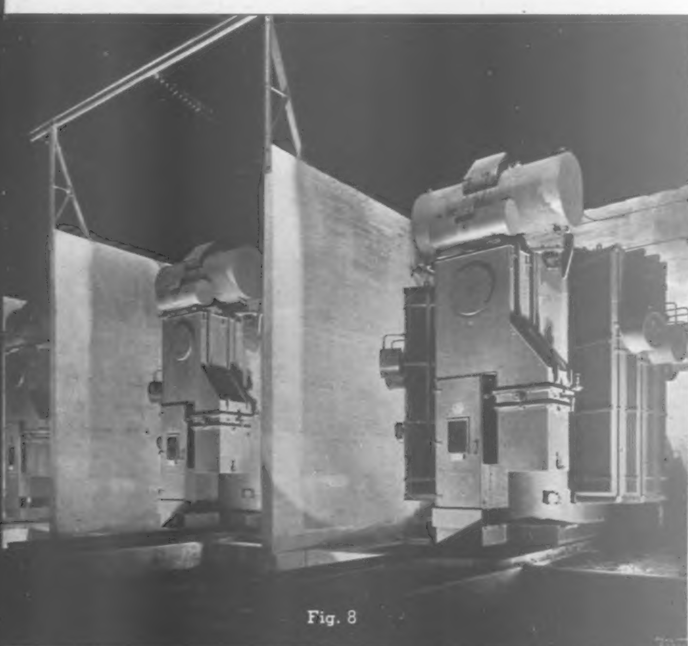


Fig. 8

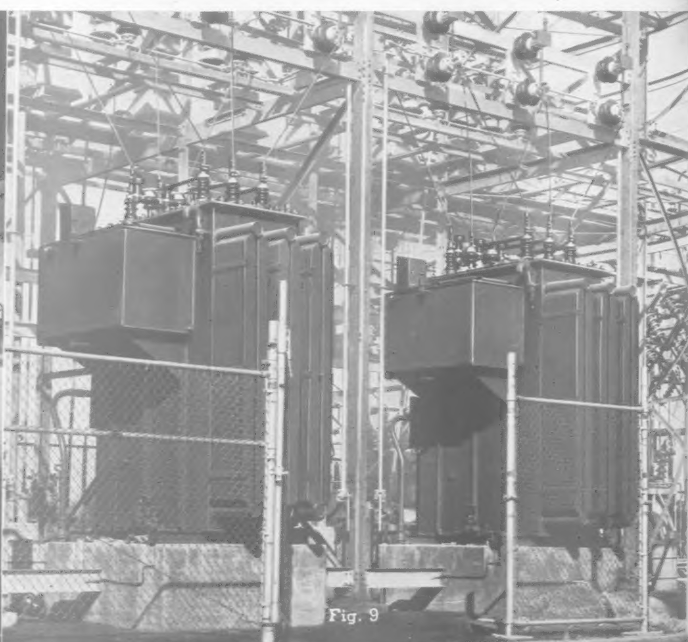


Fig. 9

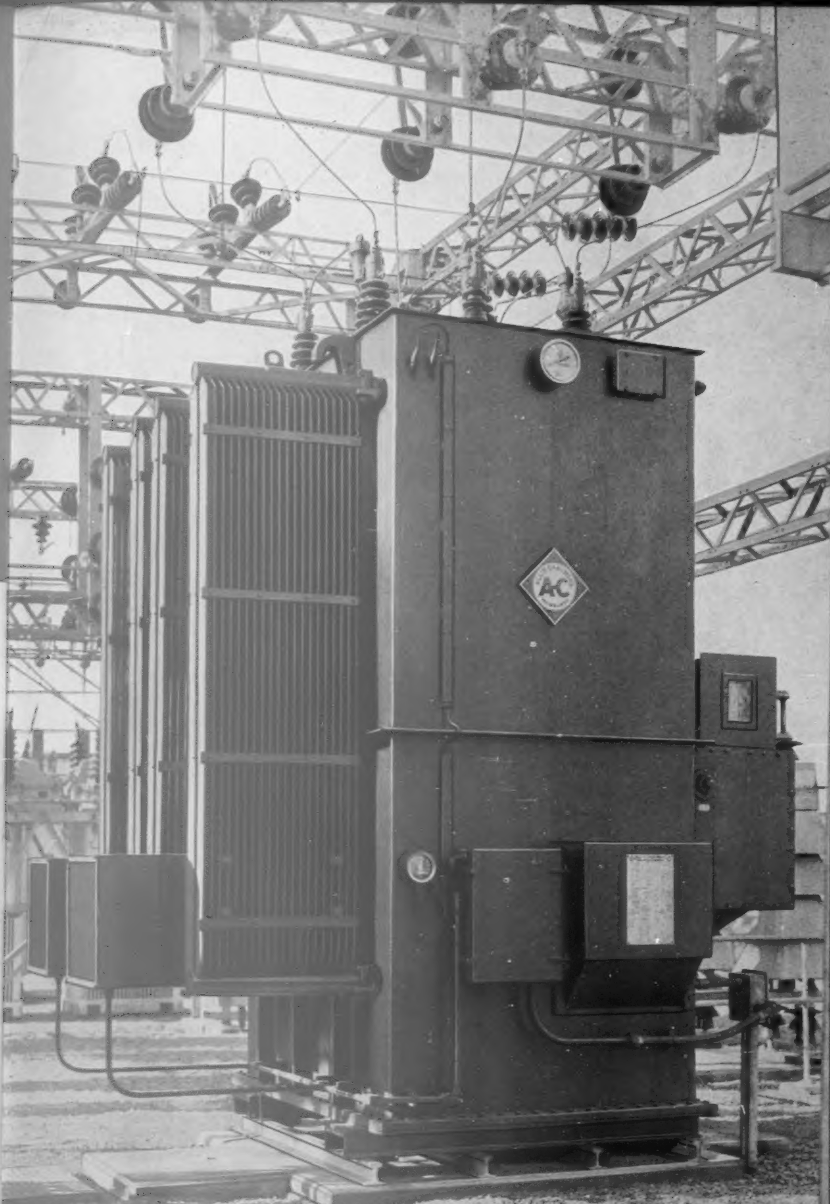


Fig. 10

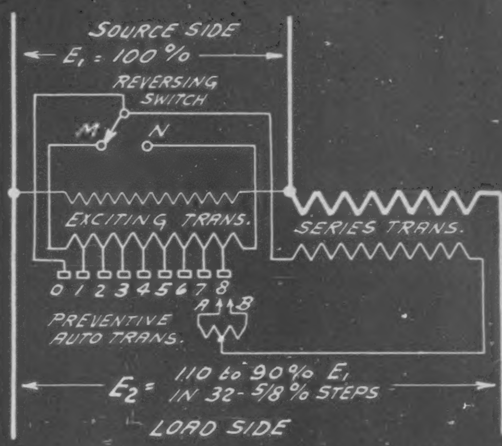


Fig. 11

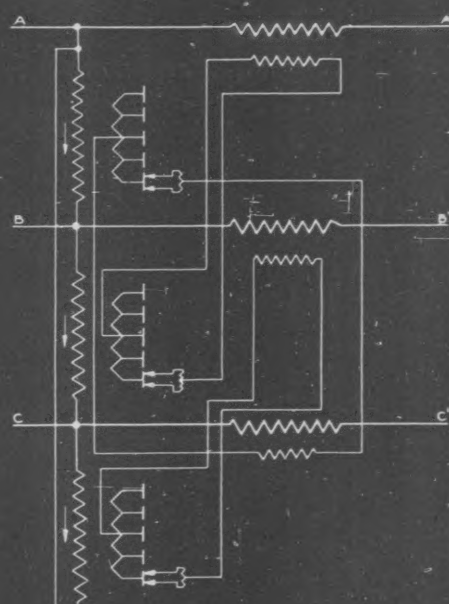


Fig. 12

No. 2 of Fig. 7, and Fig. 9, typical equipment where the auxiliary circuit breakers are omitted.

• Power transformers for use as step-voltage regulators

Another trend which has manifested itself is one toward the design of power transformers for use as step-voltage regulators arranged to adjust voltage in small steps. These units can be built in almost any size for any voltage to cover a 20 per cent range in steps as small as ⅝ per cent. Fig. 10 illustrates a typical unit for 46 kv operation on a 13,333 kva circuit. The schematic diagram is shown in Fig. 11. It will be noted that the ⅝ per cent steps are obtained with but eight physical taps in the windings.

• Growth of phase angle control under load

The perfection of tap changing under load equipment has made possible reasonably inexpensive equipment for phase angle control under load, and a steadily increasing number of these units are being installed. Phase angle control under load consists merely of means for impressing in the line circuit a variable voltage which is NOT in phase with the line to neutral voltage. This is done by combining voltages from different phases of a three-phase circuit instead of from the same phase. Numerous combinations are possible, but the general method is illustrated in Fig. 12.[4]

[4] "Transformers for Combined Voltage and Phase Angle Control Under Load," by L. H. Hill, Allis-Chalmers ELECTRICAL REVIEW, Dec. 1937.

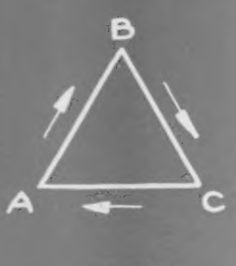


Fig. 13

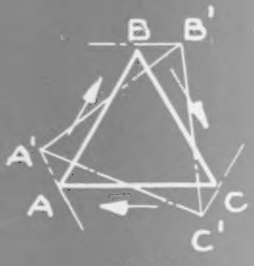


Fig. 14

Fig. 13 shows the vector relationship of the line voltages A, B, and C. To insert a voltage in each line at right angles to the line-to-neutral voltage requires adding voltages AA′, BB′, and CC′, as shown in Fig. 14. However, because the voltage AA′ is in phase with the voltage CB, BB′ is in phase with AC, and CC′ is in phase with BA, to obtain these voltages it is only necessary to connect the primary of the series transformer across a winding with its voltage in phase with the corresponding line voltage. One way of doing this is to connect the exciting transformer in delta as shown. By the use of a center tap in the secondary of the exciting transformer, the voltage can be advanced or retarded, as shown in Fig. 14.

Tap changing under load equipment for obtaining a variable phase displacement under load is exactly the same as the type of equipment used for voltage ratio control under load except for the electrical connection of the windings.

Recently there has been a tendency toward more extensive use of regulating units to give independent in-phase control and phase angle control in the same unit. Such an arrangement is merely a combination of what would otherwise be separate units. A description of a typical installation of this type is given in the article "A Major Installation of Regulating Transformers" by Henry R. Kurth, which also appears in this issue.

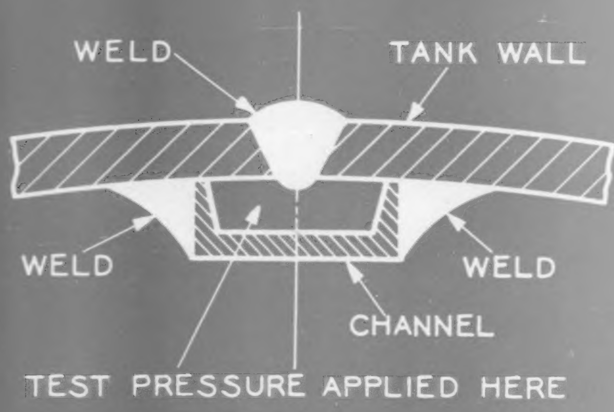


Fig. 15

• Oil-filled bushings

During the past few years the range of application of oil-filled bushings in power transformers has been extended. For applications above 66 kv, oil-filled bushings have been used for many years. Today oil-filled bushings are almost always used for 33 kv and above and, in numerous cases, even as low as 13.2 kv.

• Designing for oil-tightness

The thorough precautions now being taken in designing for oil tightness are not necessary to solve the problem of eliminating dripping leaks but to avoid even slight oil seepages which might cause stains.

Two types of joints are employed—welded joints and gasketed joints. Long microscopic leakage paths through the welds which do not show up on low pressure tests over considerable periods of time are the principal difficulty incident to the use of welded joints. High pressure cannot be applied to the entire case because of mechanical limitations. To date the best known method of making oil-tight welded joints is to use double welds with a space between, such as in Fig. 15. This space can be tested at very high pressures without applying pressure to the tank itself.

A quite different problem is encountered with gasketed joints. Certain grades of impregnated composition cork are the best all-around material for the purpose when properly applied. This type of material has a definite yield point and must not be compressed beyond this point if a proper seal is to be made. Fig. 16 illustrates a construction using composition cork correctly. Metal-to-metal

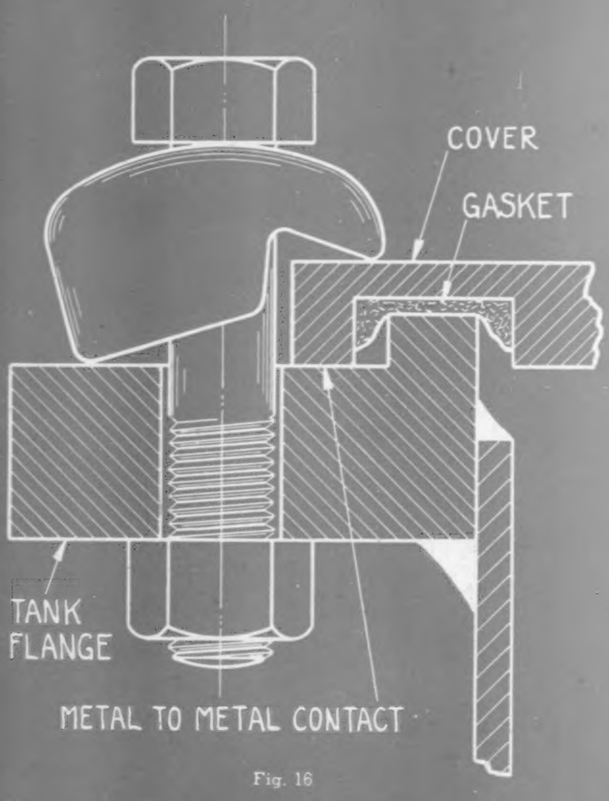


Fig. 16

contact of the mating flanges limits the compression of the cork to a predetermined amount. The joints in the cork strips are important and should be of the machined-scarfed type at least one and one-half inches long. With the proper design and installation, this type of gasketed joint will stay tight for the life of the transformer. Walking on the cover or tightening the bolts too tight will not harm it.

• Multi-windings

Three-winding units are no longer unusual. The modern power transformer can be readily built with three windings of any combination of voltages and almost any combination of reactances between windings. A few four-winding power transformers have been built; one of the largest is shown in Fig. 17.

• Building for special requirements

Power transformers designed to meet very special requirements are increasing in number. Nowadays few large power transformers are being manufactured which do not in some way present their own particular problems. On the other hand, some details which formerly made a transformer "special" are now commonly furnished. The use of terminal compartments is becoming quite general. No-load tap changers are ordinarily included, and in many cases they are conveniently arranged for operation from the side of the case.

A bank of transformers illustrating particularly well the general trend toward the inclusion of more and more accessories, special features, etc., is shown in the illustration on page 7 in the article by Henry R. Kurth. Here the transformers include not only two three-phase tap changing under load equipments per unit, but terminal compartments for both the high and low sides, three-position disconnecting and grounding switches for the incoming lines, three separate inert gas equipments for various elements of the transformers, and the entire tank shell removable from the base instead of only a removable cover.

• Summary

It can be seen that much constructive progress has been made on the problems of designing for impulse voltages, the use of dielectric flux control, designing for absolute oil-tightness, more general application of load tap changing equipment both in straight transformers and regulating units for voltage and phase angle control, multi-winding units, forced air blast equipment, and inert gas protection. Improvements in the methods of manufacture, greater diversity of service rendered and simplified refinements to meet whatever requirements the scope of transformer operation may lead to are ever-present problems in the transformer field, and these factors will naturally have their effects on transformer designs of the future.

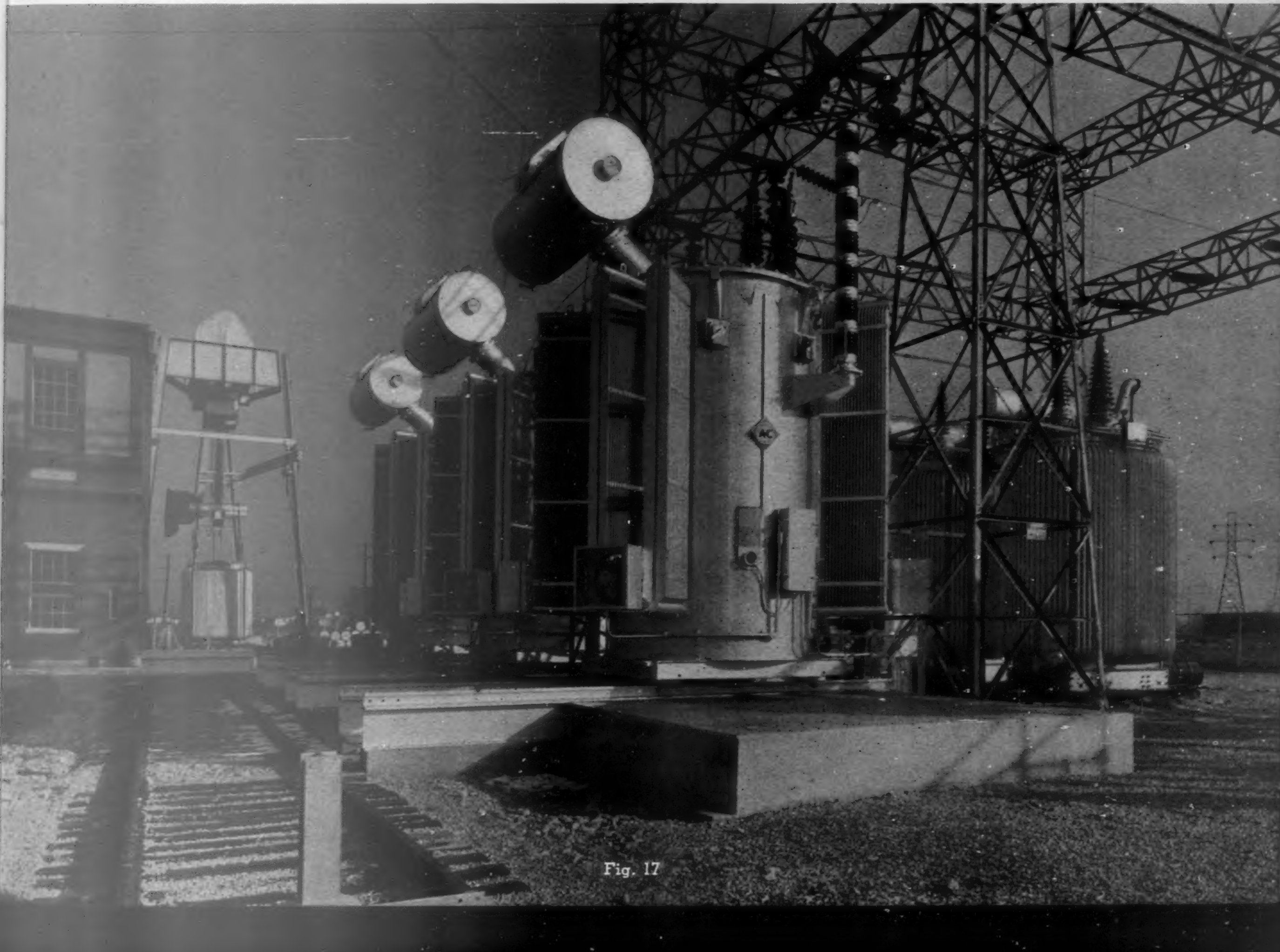


Fig. 17

ELECTRIC MOTOR DRIVES FOR GYRATORY CRUSHERS

• C. S. Lincoln
CRUSHING AND CEMENT DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

During the early years of this century the use of steam power for driving rock and ore crushing plants was all but universal. Each power plant had its usual set of boilers, steam engine, and other auxiliary equipment. A belt or rope drive connected the engine to the main line shaft. From the line shaft all the crushers, elevators, and screening equipment were driven by pulleys and rubber belting. Auxiliary rope drives were used for remote drives in the plant and steam lines were run to the quarry to drive water pumps.

• Electric motor drives introduced

About 1910 individual electric motor drives for crushers came into general use. In some of the larger plants, steam-engine and turbine-driven alternators were installed to produce electric current for driving gyratory crushers and other auxiliary equipment. Near cities, and in more populous parts of the country where central station power was available, crushers were driven by alternating-current electric motors run by power supplied from the local public utilities.

Most of the earlier electric motor drives for crushers were squirrel cage induction motors. These squirrel cage motors were belted to the crushers by means of rubber belts having the same center distance between motor and crusher as was used for line shaft drives. Center distances of 16 to 24 feet were the accepted practice.

The high inrush of current to large squirrel cage motors at the time of starting created considerable disturbances in the transmission lines, and for this reason squirrel cage motors of the larger sizes were eventually prohibited in some localities.

The introduction of slip-ring motors reduced the amount of current required for starting and gave greater starting torque than was possible with standard squirrel cage induction motors.

In the earlier installations there was a tendency to use larger motors than were actually needed. This was due not to lack of knowledge about horsepower requirements but to the desire of the operators to be certain that ample power would be available for any contingent load. In plants having a large primary crusher and several smaller reduction crushers, together with various belt conveyors, elevators, and screens, a considerable number of motors was needed; and with each motor being of such size as to be suitable for the maximum power requirement of the machine with which it was used, it can readily be seen that when a plant was operating under normal conditions many of

AT LEFT: A gyratory crusher fed by a vibrating screen.

the motors were underloaded. The use of oversize motors therefore resulted in low power factor for the entire plant, and the operators who purchased the power began to be penalized for this condition.

To overcome low power factor, many plants installed synchronous motors drawing a leading power factor to drive the primary crushers.

• Advantages of using synchronous motors

These synchronous motors were often belted to the crushers — in other cases they were direct connected. A direct-connected motor of any type is particularly advantageous where the primary crusher is installed in a pit, as it reduces the space requirements. The pit does not have to be enlarged to provide the long belt centers required with belt or manila rope drives.

Since synchronous motors may be sensitive to the heavy shock loads to which crushers are always subjected, it has been found desirable in certain installations to equip the countershaft of the crusher with a small flywheel to prevent the synchronous motor from pulling out of step when the crusher receives the shock caused by dumping a carload of heavy stone into it. For this same reason, a direct-connected motor is frequently coupled to the crusher pinion shaft by means of a flexible coupling. Magnetic clutches are also sometimes used between synchronous motors and crushers to reduce the shock on the motor.

• Belt drives

For large size gyratory crushers installed in the period from 1915 to 1925, rope drives using the so-called English system were installed between motor and crusher. These drives proved more economical than the heavy belts previously used. Most of the motors for this service were of the three-bearing type on account of the wide-face sheaves or pulleys required.

BELOW: A 10-in. reduction crusher direct-connected to motor.

With the introduction of the multiple "V"-belt drive (Below), the problem of crusher drives was greatly simplified, as this drive has the advantage that it can be installed on short centers, thereby conserving space. It can be applied equally well to a slip-ring, synchronous, or squirrel cage motor. It is simply necessary to see that the sheave on the crusher is made heavier than otherwise needed so as to give the slight flywheel effect desirable for this class of work.

Another advantage of the multiple "V"-belt driven gyratory crusher is that, with the ratio of reduction which can be safely used with this drive, a much higher speed, and consequently less costly, motor can be used. Further, if a change in the speed of the crusher is found desirable because of a change in operating conditions, the adjustment can be made at comparatively little expense. In most cases it involves merely the changing of one of the sheaves. In contrast, with the direct-connected drive, a slow speed, and consequently more costly, motor is required, and the speed cannot be readily altered.

A unique arrangement in the motor drives of gyratory crushers is illustrated on page 28, which shows a high-speed, gyratory crusher with the motor located above the spider. A vertical motor is direct connected to the crusher eccentric by means of a shaft extending through the crusher main shaft, which is bored out to receive it.

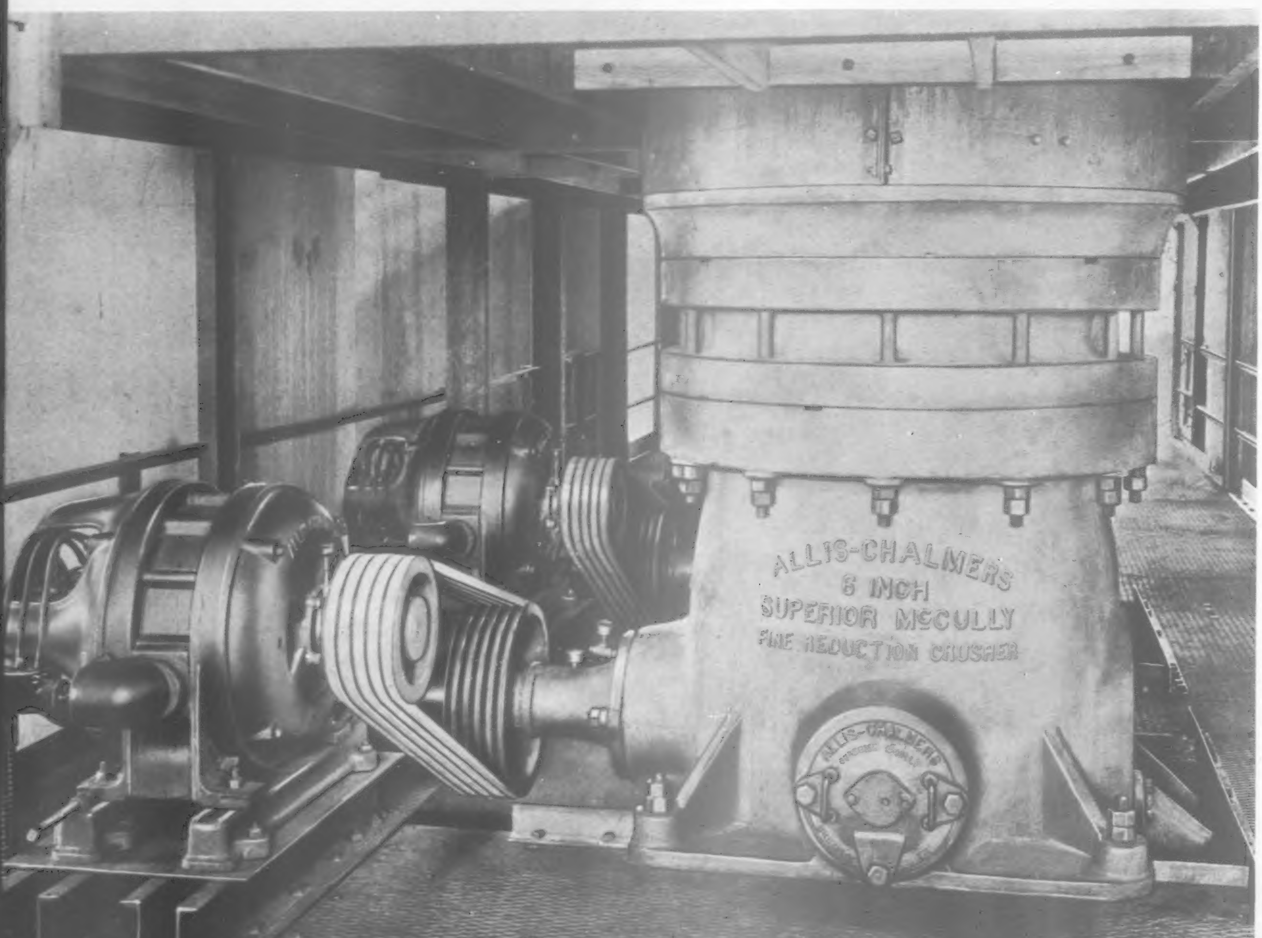
In some cases the crusher is driven direct to the eccentric by means of a motor located below the eccentric.

• Starting control

The control used for starting motors driving rock and ore crushers should be rugged. Starters should preferably be equipped with thermal overload relays that will take a heavy momentary overload without tripping but will provide motor protection in case of sustained overload.

As it is a difficult task to remove stone from a large machine partly filled with stone and stalled because of a power interruption, many devices have been proposed to start crushers under load. Manufacturers of crushers have been reluctant to countenance this practice as it undoubtedly puts much extra stress on the crusher. Many crusher motors are, however, equipped with reversing switches so that the motor and crusher may be reversed slightly to take the load off the crusher eccentric. A partial turn of the eccentric will do this in many cases, and the crusher can then be started without spending the time required to take out the stone.

BELOW: Two 50 hp motors operate 6-in. crushers.



PATENT INTERFERENCE

• Leo Teplow
PATENT ATTORNEY . . . ALLIS-CHALMERS MANUFACTURING CO.

To the lay mind, the word "Interference" conjures visions of a large stadium, teamwork and touchdowns. To the patent lawyer, "Interference" usually means a headache.

An interference, in patent parlance, is a proceeding to determine which one of two or more inventors who claim to have made the same invention is entitled to be declared the first inventor and to receive a patent covering this invention.

Let us assume that D. Velop is a draftsman working for a shoe machinery manufacturer in Bangor, Maine. When business tapered off during the depression, D. Velop found himself on a payless vacation of indefinite duration. Being of an original and inventive turn of mind, he went to work in his basement on several ideas which had been floating around in his mind, but which he had had no time to work on previously. After weeks of alternate anguish and bliss (the way of the inventor, like that of the transgressor, is hard, strewn with many false promises of success), he emerged triumphantly clutching a contraption of tin cans and bent wire. "I got it!"

"Got what?" asked patient, long suffering Mrs. D. Velop. (The way of an inventor's wife is even harder.)

"A mousetrap! A successful mousetrap! The world will beat a path to our door."

"But we've got a path. And besides, how can anybody make a path with a mousetrap?" Her worst fears were realized. The loss of his job and the constant tinkering down in the cellar had unsettled her husband's mind.

But Mr. D. Velop was quite sane. That is, quite sane for an inventor. He had invented a mousetrap with easily removable jaws, so that the jaws could be discarded with their victim, leaving no tell-tale odor to warn other mice.

• Consults attorney

With the unquenchable enthusiasm possessed only by inventors and reformers, Mr. D. Velop persuaded his friend Pat. Attorney to undertake to prosecute an application for a patent on his new and useful invention. Mr. Pat. Attorney, normally a level-headed lawyer, in this instance agreed to file and prosecute a patent application for a share of the proceeds from the sale of the invention.

Let us pass quickly over the next year or two, while Mr. D. Velop alternately tries to sell his invention, without success, and works on the development of other revolutionary inventions. Every month or two he inquires about how that patent is coming along, but his friend Pat advises patience. "Rome wasn't built in a day. It takes time to get a good patent."

Then one day Pat. Attorney walked in on D. Velop while the latter was hard at work on an improved oil-filter. "Cheap to make. Millions of them being used. Why, General Motors alone..." he was muttering to himself.

"Hold on, D. V., let's get back to mousetraps," interrupted Pat.

"Oh, mousetraps. Did we get the patent?"

• Interference declared

"No, not yet. Fact is, we're in trouble. The Patent Office has just declared an interference."

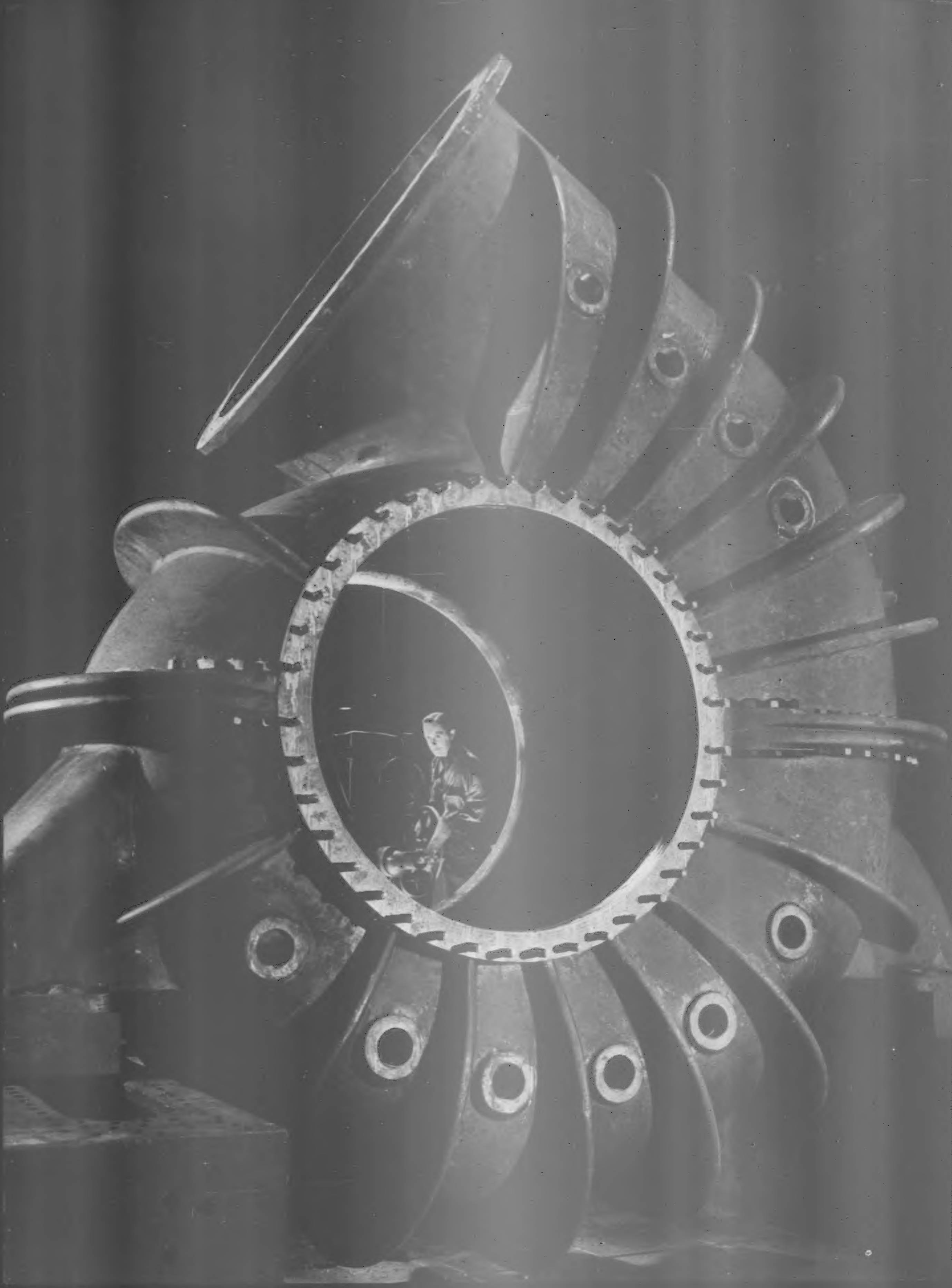
"Interference? What's the Patent Office got to do with interference?"

"Plenty. Some other inventor got the same idea, and filed a patent application on it. The Patent Office has to decide which of the two is the first inventor. The first inventor will get the patent."

"Who is the other fellow? Bet he stole it from me." D. Velop was quite bitter.

Pat sat down on the cellar stairs. "Not necessarily, D. V. Sometimes several people get the same idea entirely independently, and about the same time. The other inventor is named N. Ventor, he lives in Oshkosh, Wisconsin, and the patent application is assigned to Rattatorium, Inc., one of the biggest manufacturers of mousetraps in the country. Looks like we're going to have our hands full. When did you first get the idea of a mousetrap with removable jaws?"

"Oh, seven or eight years ago."



"Do you know exactly when? Did you make sketches or models or tell any one else about it?"

• Complications arise

"Well, I first started thinking about it about 1930. We were getting cuts in pay about that time, and started buying cereal and flour in large quantities because it was cheaper that way. And the rats and mice got into it. The traps weren't much good. After the first mouse in each trap, the others wouldn't come anywhere near it. It was then that I got the idea that if it had removable jaws I could throw them away and replace them after each catch, and the mice would keep coming."

"Did you build a mousetrap like that about that time?"

"No. I thought about it then, but I didn't have time to work on it, and I didn't do a thing about it until I got laid off in 1936. Then I remembered about my idea, back in 1930, and worked on it a couple of weeks. As soon as I had a really good model built, I showed it to you and asked you to get that application filed."

"In that case, D. V., your idea back in 1930 isn't going to do us a bit of good. It takes two things to complete an invention — getting the idea, or conception, and proving that it works by making a reduction to practice. Now, you got the idea in 1930, but did nothing about it until you started work on your model some time in 1936. That's the date of your invention, then, 1936 and not 1930."

"Then the fact that I thought of the idea way back in 1930 isn't going to do me a bit of good?"

"Not a bit. If, when you got the idea, you had made a working model, or if you had filed an application for patent then, or if you had worked on your idea diligently until you had a model or a patent application, your date of invention would have been 1930. Filing an application for patent is considered the equivalent of making a working model for this purpose. The only way an early date of conception can redound to your benefit would be to show that you have been diligent from the time an opposing party, like N. Ventor, became active, until the time you built your working model or filed your patent application. But cheer up, D. V. All is not lost yet. Maybe this man Ventor didn't get his idea until after you started working on your model, anyway.

"Well, we've got to file a preliminary statement now. Let's get the dope for that. When did you start working on your model? When did you finish it? Whom did you show it to? Did you make a signed, dated sketch and have somebody witness it? What evidence have you of the dates of your model, etc.?"

AT LEFT: Drilling a 72-in. centrifugal pump casing.

• No documents

Poor D. Velop was bewildered. As happens too often with other inventors, he had made no sketches or written description. He had explained his invention to no one until the day he had finished his model and showed it to his wife and oldest son.

Fortunately, Pat. Attorney had been more careful. He had written a memorandum on the day D. Velop had explained his invention to him. The memorandum was dated and signed, and contained a statement concerning the date when the model had been completed, two weeks previously. While this was not as desirable as earlier sketches and description which might have been prepared by D. Velop, it was something.

This is but one reason for keeping adequate witnessed, dated records concerning the progress of an invention. There are other advantages to doing so. But if only for the advantage it gives him in case of possible interference, every inventor should hang up a large sign in his work shop:

**MAKE A SKETCH AND WRITTEN DESCRIPTION OF EVERYTHING YOU DO—
SIGN AND DATE ALL SKETCHES AND DESCRIPTIONS—
HAVE THEM WITNESSED AND DATED—
PRESERVE THEM!**

Every inventor should keep such a set of instructions in his workshop — AND ACT ACCORDINGLY. That is the best interference insurance and will save him and his attorney many a headache.

On the basis of Pat. Attorney's memorandum, a preliminary statement was prepared and sworn to by D. Velop, concerning the critical dates of his invention; and the preliminary statement was filed in the Patent Office. Shortly thereafter a letter from the Patent Office stated that the preliminary statements of both parties were approved.

Thereupon Pat. Attorney ordered a copy of N. Ventor's application from the Patent Office, and they discovered that N. Ventor's invention was quite similar to D. Velop's, with slight differences. "Well, we still have a chance," remarked Pat. Attorney, "your opponent didn't file his application until a year after yours was filed."

"That means I win, doesn't it?" D. Velop was quite eager.

• Motion period

"Not yet a while, D. V. It means that you have a better chance of winning because you are the senior party, and the junior party has the burden of proof. Unless he can show by a preponderance of evidence that he is the first inventor, you will get the decision. After the motion period is over, we can look at N. Ventor's preliminary statement, and see how his dates compare with yours."

"Well, what's this motion period? Funny name for a time when we just sit still and do nothing."

"The motion period is a time set by the Patent Office to bring any motions either party desires to have considered. For example, we may think that there are other patentable features common to your invention and his. In that case we move to add other counts to the interference defining those common patentable features. Or we may think that N. Ventor has no right to claim the same invention. In that case we may move to dissolve the interference on that ground. Or there may be other similar preliminary steps we want to take. That's what the motion period is for."

"Well, what do we want to do in this case?"

"Maybe we'd better not do anything. His invention is very close to yours. There's no question about his right to make your claims. I think the claims are patentable. All the common patentable features are included in the interference already. Let's just wait and see what N. Ventor does."

The months slipped by. D. Velop was having trouble with his filter. It filtered all right when it was new, but soon became clogged and was too expensive to replace. Maybe he'd better go back to mousetraps. He wondered how that interference was coming along. He disconnected his soldering iron, put on his threadbare business suit, and went over to see Pat.

• Settlement

"Good news for you, D. V. The motion period ended without anybody filing any motions. That saves us time and effort. Some of those motions can make awfully hard work. And when I sent for a copy of N. Ventor's preliminary statement, I found that he didn't even think of the idea until after your model was completed. That makes it a clean case for us. Of course, there may still be a lot of expense to take testimony, which includes examination and cross examination, and have the whole thing transcribed and printed. That's expensive business. But maybe that can be avoided. Just got a letter from N. Ventor's attorney suggesting that we settle the matter of priority between us. And if we can show them, by documentary evidence, that you're the first inventor, they are ready to concede priority to you, thereby avoiding all this expense on both sides. And they'd like to buy your invention."

"Whoops! And if we don't settle?"

"Well, there'll be the expense I spoke of. I think you'd win in the end and get your patent anyway. You might be able to sell the patent to someone else. Rattatorium, Inc., might lose interest and go to something else if you don't meet them halfway now. They're the logical people to work under the patent, because they're apparently developing and experimenting with that very thing right now. Why not see what they'll offer?"

There's little to add, except that they lived happily ever after. D. Velop not only assigned his invention and patent application to Rattatorium, Inc., for a sufficient amount to cancel his depression debts, but also obtained a job in Rattatorium's research laboratory, where he could tinker to his heart's content and get paid for it.

• Insurance

Lest the gentle reader conclude that an interference is not such a bad experience after all, he should be reminded that the particular interference described above was an abbreviated, streamlined affair; that an interference—which includes motions (during the motion period) which are opposed by one or more of the parties; testimony by the inventors and their witnesses and experts; extensions of time to obtain information from parties hard to locate; and appeals to the Board of Appeals and possibly the courts — may consume years of time and more money than most inventors have available. And when the interference involves three or more parties, as happens not infrequently, all the factors are complicated tremendously.

The most touching aspect of any interference proceeding is the man who may actually have been the first inventor, but whose records are in such chaotic condition that he is unable to substantiate his claims. The history of interference proceedings has indicated the fallibility of human memory and the unreliable nature of verbal evidence uncorroborated by documentary evidence. Therefore more and more weight is placed on documentary evidence, on written records made contemporaneously with the acts to which they pertain. Not infrequently the man who may actually have made the contested invention subsequently to the first inventor receives a valid patent on it, because the first inventor kept no records and therefore could not prove his case.

If this be considered unjust, let it be remembered that in order to prevail in legal matters a person must have not only legally enforceable rights, but also evidence with which to prove his rights. The keeping of accurate records is a cheap form of insurance for the attainment of justice.

While not directly pertinent here, it may be added that accurate contemporaneous records are equally important for other reasons. It is sometimes important to prove the date of invention of subject matter years after a patent has been granted on it to sustain its validity.

The importance of documentary evidence in proceedings relating to patents and inventions can hardly be overemphasized.

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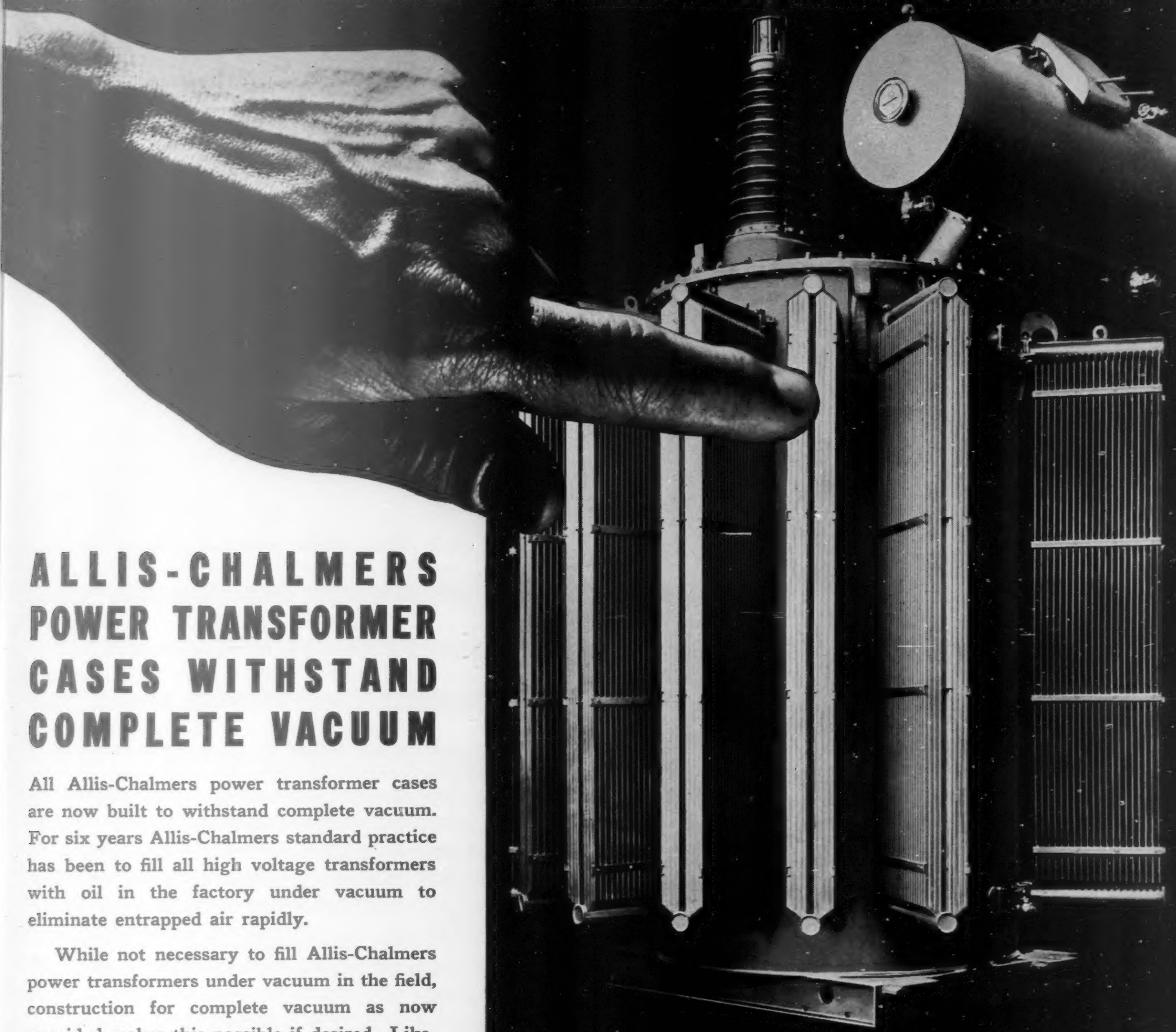

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